BNL 867 (AS-18)

BROOKHAVEN NATIONAL LABORATORY

ANNUAL REPORT
July 1, 1964

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

DISCLAIMER

BNL 867 (AS-18)
(General, Miscellaneous, and Progress Reports - TID-4500, 36th Ed.)

ASSOCIATED UNIVERSITIES, INC.

COLUMBIA UNIVERSITY

CORNELL UNIVERSITY

HARVARD UNIVERSITY

JOHNS HOPKINS UNIVERSITY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PRINCETON UNIVERSITY

UNIVERSITY OF PENNSYLVANIA

UNIVERSITY OF ROCHESTER

YALE UNIVERSITY

Annual Report

July 1, 1964

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 fourteenth in a series of unclassified Annual Reports, gives an account of the progress of the Laboratory during the period July 1, 1963–June 30, 1964, and its plan for the future. It is submitted under the terms of Contract No. AT-30-2-GEN-16 between Associated Universities, Inc., and the Atomic Energy Commission.

Previous reports in this series are:

BNL 74 (AS-4) July 1, 1950
BNL 131 (AS-5) July 1, 1951
BNL 196 (AS-6) July 1, 1952
BNL 246 (AS-7) July 1, 1953
BNL 303 (AS-8) July 1, 1954
BNL 364 (AS-9) July 1, 1955
BNL 426 (AS-10) July 1, 1956
BNL 462 (AS-11) July 1, 1957
BNL 523 (AS-12) July 1, 1958
BNL 560 (AS-13) July 1, 1959
BNL 632 (AS-14) July 1, 1960
BNL 682 (AS-15) July 1, 1961
BNL 742 (AS-16) July 1, 1962
BNL 806 (AS-17) July 1, 1963

PRINTED IN USA
PRICE $6.00

Available from the
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards
U.S. Department of Commerce
Springfield, Virginia

December 1964 2400 copies

CONTENTS

Brookhaven National Laboratory is operated by Associated Universities, Inc., under contract with the United States Atomic Energy Commission. Nine northeastern universities sponsor Associated Universities, Inc. Two representatives from each university, one a principal administrative or corporate officer and the other a scientist, form the Board of Trustees of AUI. In addition, the Board itself selects three Trustees-at-Large. Their purpose is to insure adequate representation of any scientific discipline in which the corporation may undertake work and to provide general flexibility in methods of operation. The composition of the Board as of June 1964 is given below. The officers of AUI are shown on the organization chart for the Laboratory (Figure 1). AUI has appointed five visiting committees to Brookhaven National Laboratory to provide a continuing independent evaluation of the research program. The committees cover the fields of biology, chemistry, medicine, nuclear engineering, and physics, and report annually to the Board of Trustees.

BOARD OF TRUSTEES
OF
ASSOCIATED UNIVERSITIES, INC.
AS OF JUNE 30, 1964

Ralph S. Halford	Columbia University	I.I. Rabi
Franklin A. Long	Cornell University	Boyce D. McDaniel
L. Gard Wiggins	Harvard University	William H. Sweet
Allyn W. Kimball	Johns Hopkins University	P. Stewart Macaulay
Peter T. Demos	Massachusetts Institute of Technology	Carl F. Floe
Val L. Fitch	Princeton University	Ernest F. Johnson
Richard H. Chamberlain	University of Pennsylvania	Carl C. Chambers
LaRoy B. Thompson, *Chairman*	University of Rochester	Ernst W. Caspari
C. Hamilton Sanford	Yale University	Vernon W. Hughes

Trustees-at-Large

Edward M. Purcell, Harvard University — Thomas Gold, Cornell University

Robert F. Bacher, California Institute of Technology

Annual Trustees

Edward Reynolds, Harvard University (retired) — Leo Goldberg, Harvard University

William D. McElroy, Johns Hopkins University

Honorary Trustee

Frank D. Fackenthal, Columbia University (retired)

Ex Officio

Edward Reynolds, *President*

VISITING COMMITTEES

Biology

ARMIN C. BRAUN, *Chairman*
Rockefeller Institute

RAYMOND E. ZIRKLE
University of Chicago

MARCUS M. RHOADES
Indiana University

ARTHUR K. SOLOMON
Harvard Medical School

SIDNEY P. COLOWICK
Vanderbilt University

COLIN S. PITTENDRIGH
Princeton University

CHRISTIAN B. ANFINSEN
National Institutes of Health

ALVIN NASON
Johns Hopkins University

Chemistry

PHILIP H. ABELSON, *Chairman*
Carnegie Institution of Washington

CLYDE A. HUTCHISON, JR.
University of Chicago

WILLIAM N. LIPSCOMB
Harvard University

ISADORE PERLMAN
University of California at Berkeley

WILLIAM E. McEWEN
University of Massachusetts

HENRY TAUBE
Stanford University

Medicine

A. BAIRD HASTINGS, *Chairman*
Scripps Clinic and Research Foundation

BRONSON S. RAY
New York Hospital–Cornell Medical Center

LOUIS H. HEMPELMANN
University of Rochester

WILLIAM B. WOOD, JR.
Johns Hopkins University

C. PHILLIP MILLER
University of Chicago

SHIELDS WARREN
New England Deaconess Hospital

MAURICE B. VISSCHER
University of Minnesota

GEORGE Z. WILLIAMS
National Institutes of Health

Nuclear Engineering

SIDNEY SIDGEL, *Chairman*
Atomics International

CHARLES D. CORYELL
Massachusetts Institute of Technology

IRVING KAPLAN
Massachusetts Institute of Technology

ALBERT R. KAUFMANN
Nuclear Metals, Inc.

HERBERT GOLDSTEIN
Columbia University

RICHARD N. LYON
Oak Ridge National Laboratory

JOHN P. HOWE
Cornell University

LOMBARD SQUIRES
E.I. du Pont de Nemours and Co.

Physics

POLYKARP KUSCH, *Chairman*
Columbia University

ROBERT R. WILSON
Cornell University

R.E. MARSHAK
University of Rochester

JOSEPH L. FOWLER
Oak Ridge National Laboratory

W. CONYERS HERRING
Bell Telephone Laboratories, Inc.

LOUIS W. ALVAREZ
University of California at Berkeley

MARVIN L. GOLDBERGER, Princeton University

Figure 1.

ASSOCIATED UNIVERSITIES, INC.

ORGANIZATION CHART

JULY 1964

BOARD OF TRUSTEES
L.B. THOMPSON, CHAIRMAN
VISITING COMMITTEES

PRESIDENT
E. REYNOLDS
SECRETARY - C.F. DUNBAR
ASSISTANT SECRETARY - N.P. RATHVON, JR.
CONTROLLER - L.R. BURCHILL
TREASURER - J.S. ALEXANDER
ASSISTANT TREASURER - A.F. LORD

BROOKHAVEN NATIONAL LABORATORY

DIRECTOR
M. GOLDHABER
-35-
DEPUTY DIRECTOR
C. WILLIAMS
ASSOCIATE DIRECTOR
C.E. FALK

ASSISTANT DIRECTOR, SCIENTIFIC PERSONNEL - R.C. ANDERSON
ASSISTANT DIRECTOR, BUSINESS MANAGEMENT & BUSINESS ADMINISTRATION - W.J. CATACOSINOS
ASSISTANT DIRECTOR, TECHNICAL SERVICES - G.N. GLASOE
ASSISTANT DIRECTOR, PLANT ENGINEERING & OPERATIONS - S.M. TUCKER

BUDGET OFFICER - H.R. CORT
CONTROLLER - L.R. BURCHILL
LEGAL COUNSEL - C.F. DUNBAR; ASSOCIATE - N.P. RATHVON, JR.

S.M. TUCKER
ASSISTANT DIRECTOR PLANT ENGINEERING & OPERATIONS

- ARCHITECTURAL PLANNING 33 — J.G. PETER
- PLANT MAINTENANCE 431 — D.E. MALLORY
- PLANT PROTECTION & SECURITY 75 — E.J. BURKE

G.N. GLASOE
ASSISTANT DIRECTOR TECHNICAL SERVICES

- PHOTOGRAPHY & GRAPHIC ARTS 57 — J.F. GARFIELD
- CENTRAL SHOPS 138 — D.N. EDWARDS

PHYSICS DEPARTMENT 390 — G.H. VINEYARD
- HIGH ENERGY PHYSICS
- NEUTRON PHYSICS & NUCLEAR STRUCTURE
- SOLID STATE PHYSICS
- CYCLOTRON & VAN DE GRAAFF OPERATIONS

CHEMISTRY DEPARTMENT 115 — R.W. DODSON
- GENERAL CHEMISTRY
- RADIATION CHEMISTRY
- ISOTOPE STUDIES
- NUCLEAR CHEMISTRY

BIOLOGY DEPARTMENT 131 — H.J. CURTIS
- GENETICS
- MAMMALIAN PHYSIOLOGY
- GENERAL PHYSIOLOGY
- BIOCHEMISTRY
- BIOPHYSICS

MEDICAL DEPARTMENT 194 — V.P. BOND
- MEDICAL RESEARCH
- RESEARCH HOSPITAL
- INDUSTRIAL MEDICINE

ACCELERATOR DEPARTMENT 412 — G.K. GREEN
- AGS
- COSMOTRON
- ACCELERATOR DEVELOPMENT

APPLIED MATHEMATICS DEPARTMENT 64 — J.W. CALKIN
- COMPUTER OPERATIONS & PROGRAMMING
- COMPUTER & PROGRAMMING RESEARCH
- DIFFERENTIAL & INTEGRAL EQUATIONS
- NUMERICAL ANALYSIS
- STATISTICS
- MATHEMATICAL PHYSICS

NUCLEAR ENGINEERING DEPARTMENT 342 — W.E. WINSCHE
- REACTOR PHYSICS
- CHEMISTRY & CHEMICAL ENGINEERING
- METALLURGY
- REACTOR ENGINEERING
- HOT LABORATORY OPERATIONS
- RADIATION DEVELOPMENT
- HIGH FLUX BEAM RESEARCH REACTOR PROJECT

INSTRUMENTATION & HEALTH PHYSICS DEPARTMENT 179 — J.B.H. KUPER
- INSTRUMENTATION
- HEALTH PHYSICS
- METEOROLOGY
- SAFETY

MECHANICAL ENGINEERING 163 — I.J. POLK

REACTORS 85 — R.W. POWELL

W.J. CATACOSINOS
ASSISTANT DIRECTOR BUSINESS MANAGEMENT & BUSINESS ADMINISTRATION

- PURCHASING 36 — B.W. QUINN
- SUPPLY & MATERIEL 83 — F.W. WALSH
- SYSTEMS & DATA PROCESSING 21 — R.E. WILLIAMS

C. WILLIAMS
DEPUTY DIRECTOR

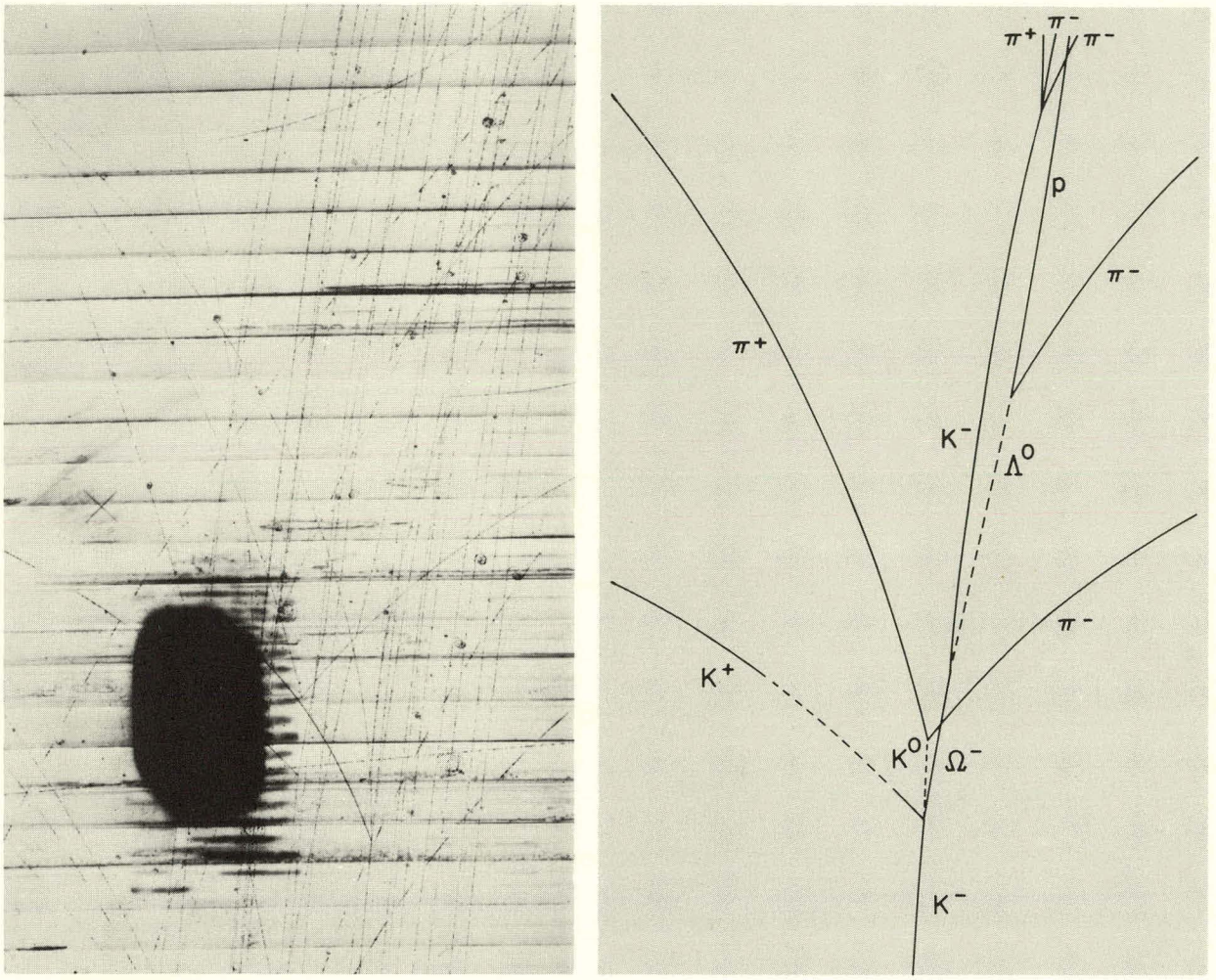
- PERSONNEL 21 — J.S. WASHBURNE, JR.
- FISCAL 40 — R.B. EBERBACH
- INFORMATION 27 — D. PULESTON

THE NUMBER OF EMPLOYEES IN EACH ORGANIZATIONAL UNIT ON JUNE 30, 1964, IS SHOWN; TOTAL FOR THE LABORATORY, 3065.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK



Photograph of the second recorded instance of the production and decay of the Ω^- hyperon taken in the 80-in. liquid hydrogen bubble chamber at the Alternating Gradient Synchrotron. The sketch beside the photograph shows the assignment of the proper particle to each track. The paths of neutral particles, which produce no bubbles in the liquid hydrogen and therefore leave no tracks, are shown by dashed lines. The presence and properties of the neutral particles are established by analysis of the tracks of their charged decay products or application of the laws of conservation of mass and energy, or a combination of both. The observation of the Ω^-, whose existence was predicted by a group of theoretical physicists, is significant in that it may be the keystone to an orderly arrangement of the previously known particles. For a complete description of the experiment and a photograph of the first Ω^- event, see the section on Physics.

Introduction

The program and activities of Brookhaven National Laboratory during the fiscal year 1964 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 ma-

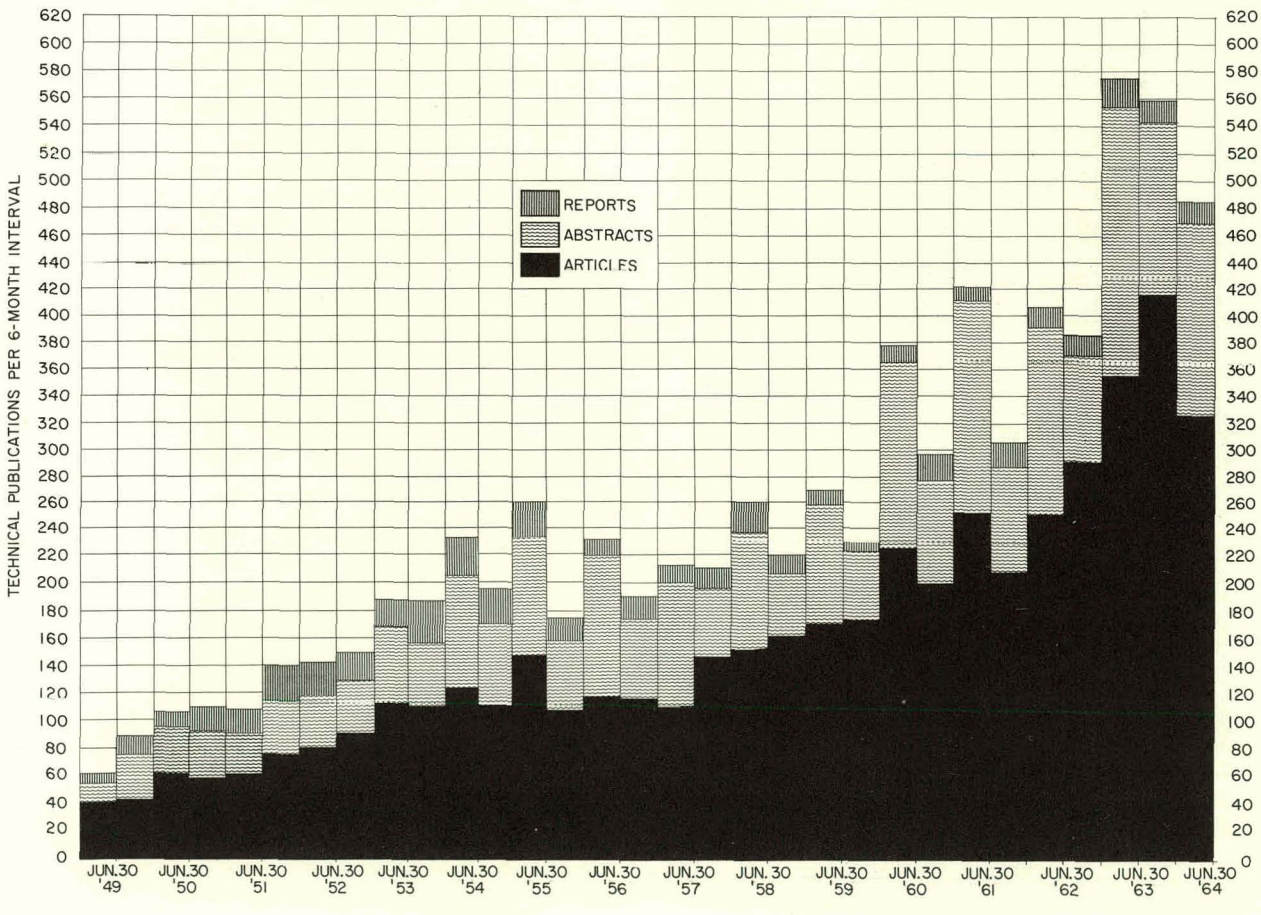


Figure 2. Technical publications.

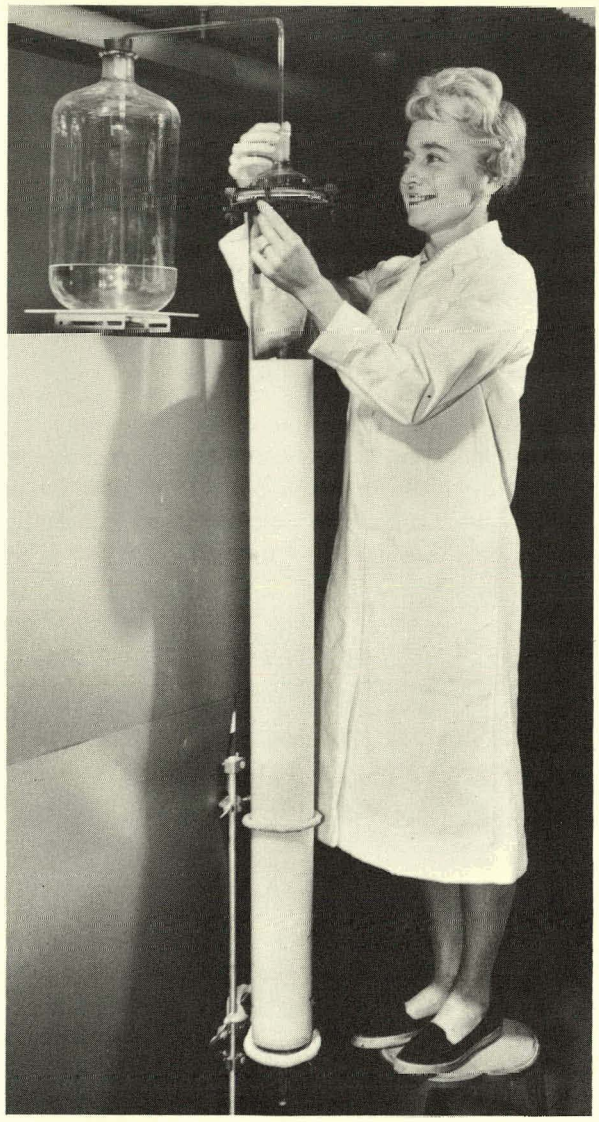


Figure 3. A paper pulp column used to separate the two forms of kynurenine, a product of the intermediary metabolism of tryptophan, a widely distributed, naturally occurring, essential amino acid. The finding of high levels of kynurenine in the urine of patients with bladder tumors and a variety of other diseases has stimulated interest in the use of C^{14}-labeled kynurenine for extensive studies of kynurenine metabolism in man. Naturally occurring kynurenine is always in the levo (L) form. Organically synthesized biological products are always obtained as a mixture of the L and D (dextro) forms, which are usually handled differently by the animal body. Both forms of kynurenine are needed for studies in humans and animals. Previous methods of chemical separation were unsatisfactory, and a new technique, paper column chromatography, has been developed. A large (5-in.-diam by 5-ft-long) glass column is packed with powdered paper pulp, and a mixture of the D and L forms of kynurenine is slowly (48 hr) flushed through the column. The two forms proceed down the column at different rates and are drawn off at the bottom at separate times as pure L-kynurenine and D-kynurenine. This process provides the first separation of kynurenine in quantities sufficient to permit studies in humans. The two C^{14}-labeled forms of kynurenine are expected to provide valuable information concerning metabolism in normal humans and in those with tumors or other diseases involving large quantities of kynurenine in the urine.

chines of the Laboratory. They range from measurement of the properties of undisturbed nuclei to study of the violent disruptions resulting from nuclear fission or from bombardment with high energy protons from the Laboratory's 3-BeV Cosmotron and 33-BeV Alternating Gradient Synchrotron (AGS).

2. STUDIES OF THE PHYSICAL, CHEMICAL, AND BIOLOGICAL EFFECTS OF NUCLEAR RADIATION. The effects of radiation are utilized to determine the characteristics of physical and chemical structures and to elucidate the more complex properties of living systems and the changes they undergo in their life and reproductive cycles. Of direct practical interest are the possible deleterious effects of radiation upon biological systems and upon various materials, for example, those involved in reactor construction. Of equal interest are the potentially beneficial effects of radiation in the treatment of 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 scattering, minute details of physical and chemical structure can be studied. Wide use is made of isotopic tracers in many fields to yield information on such matters as the mechanisms and rates of chemical reactions and biological processes.

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

actor products, and theoretical and experimental studies in the field of reactor physics.

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

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

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, Brookhaven's 33-BeV proton synchrotron (the world's largest particle accelerator), has continued to be an important center for the performance of research in high energy physics. The machine schedule of 21 8-hr shifts per week provided $\approx$6600 hr of operating time, of which 62% were used for research. Simultaneous flipping of targets at 3 separate locations allowed as many as 6 experiments to share each pulse of protons from the machine. Beam intensities of 3 to 4×10^{11} protons/pulse were routine. During the year 2.5 million photographs were taken with the 3 liquid hydrogen bubble chambers (20-, 30-, and 80-in.) in use at the AGS.

The construction of the Southwest Experimental Area to accommodate neutrino physics experiments was completed, and the primary proton beam was successfully extracted and conveyed onto a quartz target in the area on November 21, 1963. Since then a neutrino experiment utilizing a large aluminum spark chamber has been under way at this area.

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

Cosmotron

The Cosmotron, a 3-BeV proton synchrotron, continued to play an important role in high energy physics research. The demand for time on this machine has remained high, as indicated by the current 1-yr backlog of approved experiments. Maximum beam intensity was $>10^{12}$ protons/pulse, and intensities of 3 to 5×10^{11} protons/pulse continued to be routine. The Cosmotron operates on a schedule of 21 8-hr shifts per week. Of the $\approx$7900 hr available for machine operation, 70% were used for research.

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

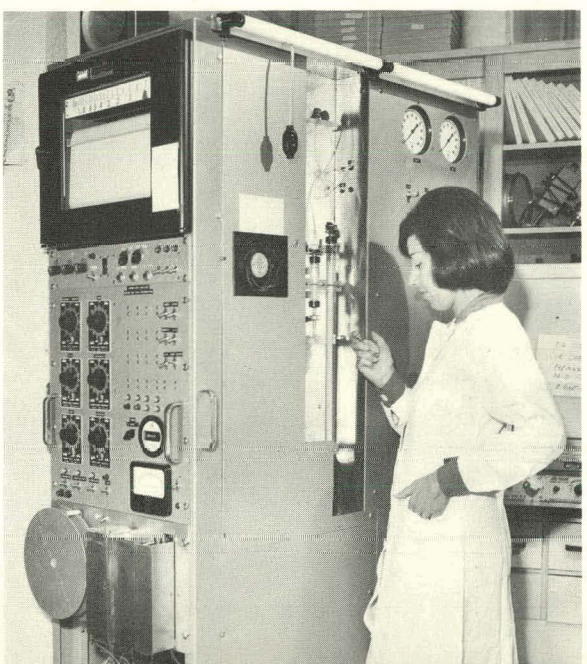
60-in. Cyclotron

The 60-in. cyclotron accelerates protons to 10 MeV, deuterons to 20 MeV, He^4 ions to 40 MeV, and He^3 ions to 30 MeV. The ability to accelerate He^3 ions is the result of the addition to the cyclotron during the past year of field correcting coils and a He^3 recirculating system. At present, internal and external beams of He^3 ions are produced routinely with intensities comparable to those for He^4. The He^3 beam is used chiefly in nuclear reaction studies but is also used for the production of neutron-deficient isotopes through the $(He^3,2n)$ and $(He^3,3n)$ reactions which have appreciable cross sections at 30 MeV. Deflected beams of up to 50 μA as well as internal and externally focused beams are available. A small external beam with momentum analysis to 1 part in 1000 is routinely used. The cyclotron was used by scientists from several Brookhaven departments as well as from eight outside institutions during the past year. Work for outside institutions and work by guests and collaborators from outside institutions accounted for $\approx$62% of the machine time. The principal activities involved nuclear reaction studies, production of radioactive materials for a wide variety of purposes, and the direct use of the beam for various studies of biological systems. The conversion of the cyclotron to variable-energy, sector-focusing operation is now planned for the

Figure 4. Part of the Laboratory's IBM 7094 data-processing system, operated by the Applied Mathematics Department since 1962. The operator is seated at the console control unit. The lights on the vertical panels and the switches or keys near the operator's left hand provide some of the facilities for man-machine interaction. In the background is a bank of magnetic tape drives; a tape-switching device at the left of the operator enables him to direct the use of all tape drives from one central position. In the lower right-hand corner stands the 21-in. cathode-ray-tube (CRT) visual display. The computer has direct control over this and the associated CRT camera recorder which record and display graphical output generated by the computer program.

Figure 5. In a Medical Department laboratory, tissue samples are being prepared for histological study in research on the effects of radiation on living tissues. Investigations of prepared histological sections with the microscope can assess the degree of radiation damage incurred by various cells and tissue structures. The tissue is sliced into very thin sections by using the microtome at the far end of the table and then stained with various dyes to accentuate the details of cellular structure.

Figure 6. Automatic amino acid analyzer used in protein structure research. The 18 amino acids found in proteins are separated chromatographically and their relative proportions are determined with a precision of within 1 to 2% in 8 hr. The instrument incorporates a number of novel features that have greatly increased its utility. A photometer with longitudinal flow cells permits accurate analysis in the range between 1×10^{-7} and 1×10^{-8} moles of each amino acid. Thus, a total amino acid analysis of a protein may be obtained with as little as 0.1 mg of material. Manual calculation of the data (an operation formerly requiring $\approx$2 hr) is eliminated by a digitizer that transmits a record of the analysis to punched paper tape in a form suitable for subsequent processing in a digital computer.



immediate future. This will provide variable-energy beams with energies of up to 40 MeV for protons, 20 MeV for deuterons, 40 MeV for He^4 ions, and 54 MeV for He^3 ions and will permit the acceleration of heavier ions. In addition to the advantages to be gained from these new capabilities for nuclear reaction studies and isotope production, the increased range (from 2 to 15 mm) of the proton beam will be of particular significance in medical and biological experiments. Model studies of the radio-frequency and magnet systems were carried out, and the design and fabrication of major components were begun. The modified cyclotron is expected to be in operation late in 1965.

Electrostatic Generator

The electrostatic generator accelerates protons, deuterons, alpha particles, and He^3 ions with beam currents up to 75 μA. The installation late in the year of a new accelerator tube increased the maximum energy at which the machine may be operated from 3.2 to 4.0 MeV, with a consequent extension of the scope of possible experiments at the facility. During the past year the machine was operated for research during 529 8-hr shifts, the highest number of shifts in any one month being 59. Fast neutron irradiations for the Medical and Nuclear Engineering Departments and the Health Physics Division accounted for $\simeq$4.4% of the time. The remainder was used for physics research carried out by scientists from Brookhaven and several outside institutions. The research at this facility centers on the determination of the properties of energy levels of light- and medium-weight nuclei excited in various nuclear reactions. Part of this work made use of the external beam-pulsing system with which it is possible to achieve a full-width time resolution of 5×10^{-10} sec.

Graphite Research Reactor

The in-pile and beam facilities of the Brookhaven Graphite Research Reactor (BGRR), which has been in almost continuous operation since 1950, are used in a variety of programs by Brookhaven personnel and by visiting scientists and engineers from other institutions. The maximum thermal neutron flux available is $\simeq2\times10^{13}$ neutrons/cm^2-sec. The reactor loading remained at 615 channels. The graphite annealing procedure to repair graphite radiation damage was carried out 18 times during the past year. A third vertical hole 4 in. in diameter was drilled in the graphite to provide an additional irradiation facility.

Approximately 35 reactor holes are assigned to BNL research departments. The 7 outside organizations availing themselves of reactor facilities (for other than routine irradiation services) under various cooperative arrangements have accounted for continuous use of an average of 4 experimental holes. A complete report on the BGRR will be found in the section on Technical Operations and Services.

Medical Research Reactor

The Medical Research Reactor (MRR) was constructed for the sole purpose of exploring the possible applications of nuclear reactors to the study of man and his diseases. Each salient feature of the reactor was designed in relation to its use for therapy and diagnosis or in the advancement of basic medical science. Operation 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 minutes.

The MRR was operated 286 times during the year for a total of 587 MWh. Further details on the MRR are included in the section on Technical Operations and Services.

Hot Laboratory

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

Critical Assembly Laboratory

The Critical Assembly Laboratory provides specialized facilities for research in reactor physics and for reactor development studies. The experimental area has five different zones, each consisting of an assembly cell and its associated control area. At present, two of the zones are being used for critical assemblies, the third has a 1-MeV pulsed neutron source (Van de Graaff accelerator), the fourth has a neutron source reactor, and a

Figure 7. A group of ten leading Soviet nuclear scientists and officials inspecting the 80-in. liquid hydrogen bubble chamber. They visited Brookhaven National Laboratory on November 19, 1963, during a reciprocal tour of unclassified atomic energy installations in this country. A group of U. S. nuclear scientists and AEC officials toured Russian atomic energy facilities in May 1963 and at that time invited the Soviet scientists to visit the U.S. The Soviet group was headed by Andronik M. Petrosyants (third from the right), Chairman of the USSR State Committee on the Utilization of Atomic Energy.

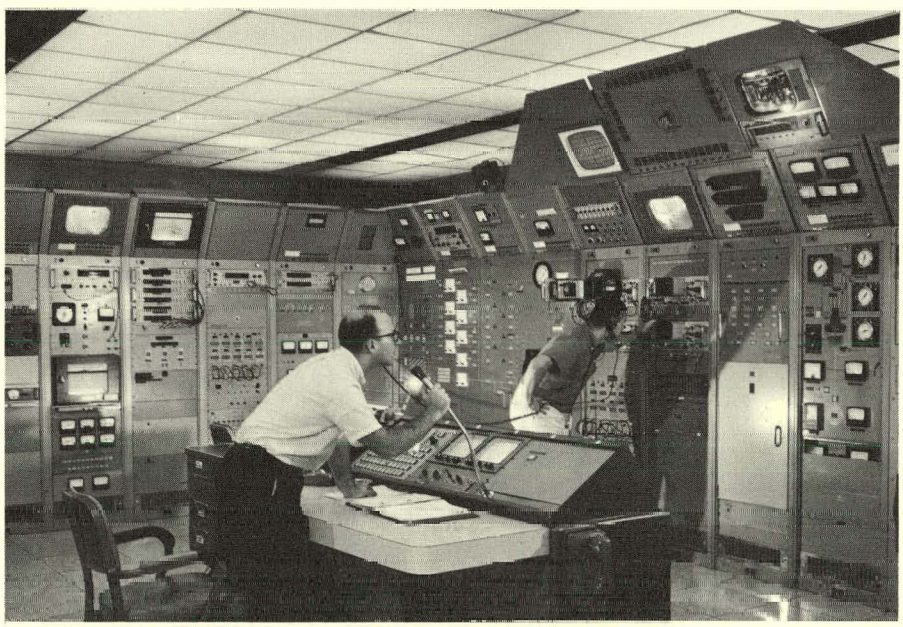


Figure 8. View of the control room of the 80-in. liquid hydrogen bubble chamber, showing some of the many instruments and controls required to monitor and precisely regulate the operation of the large, complex components and systems constituting the bubble chamber.

second neutron source reactor is being built in the fifth zone. In addition to these zones, the experimental area includes a counting room, two uranium storage vaults, an electronics shop, and a mechanical shop. An analogue computer and two digital computers, used for on-line data processing as well as standard data reduction, are also available in the experimental area.

High Intensity Radiation Development Laboratory

The High Intensity Radiation Development Laboratory (HIRDL) was officially dedicated on November 22, 1963. The dedication address was made by AEC Commissioner Gerald F. Tape. The function of the HIRDL is to obtain engineering data on a variety of radiation sources in the million-curie range and to develop more efficient techniques for handling large-scale radiation sources. This information is essential for the design of future irradiation facilities needed for a wide range of applications of radiation energy. The main design features of the HIRDL are two unique cells, one an irradiation cell for the experimental work with radiation sources, and the other a work preparation cell in which various types of sources will be prepared. The total level of radiation to be eventually employed in this laboratory is $\approx$2 million curies.

During the past year 300,000 curies of ETR-type Co^{60} sources, produced in the Engineering Test Reactor in Idaho, were encapsulated and tested. In addition, 217,000 curies of Cs^{137} were received from Oak Ridge National Laboratory, and 225,000 curies of Co^{60} were received from the Savannah River plant.

Additional information on the HIRDL is given in the section on Nuclear Engineering.

80-in. Liquid Hydrogen Bubble Chamber

In its first year of operation, the 80-in. liquid hydrogen bubble chamber, located in the North Experimental Area of the AGS, produced about 557,000 photographs. One very important experiment using the 80-in. chamber verified the existence of the previously predicted Ω^- particle.

This bubble chamber, with an effective volume of 850 liters, is the largest in the world. It is positioned inside a vacuum chamber; a magnet capable of producing magnetic fields as high as 20,000 gauss with its 280-ton steel yoke completes the assembly, which is constructed in two units that separate to give access to the chamber. The entire 450-ton chamber and magnet assembly rides upon an undercarriage and can be translated, rotated, and elevated as required by the experimental program.

More information on the 80-in. bubble chamber may be found in the section on Physics.

MAJOR RESEARCH FACILITIES UNDER DESIGN AND CONSTRUCTION

High Flux Beam Research Reactor

Construction continued throughout the year on the High Flux Beam Research Reactor (HFBR). This reactor is designed to meet the need for higher neutron fluxes that has arisen as experimental techniques have improved. The HFBR will be cooled, moderated, and reflected by heavy water; it will be fueled with 28 ETR-type flat-plate fuel elements of enriched uranium comprising a compact, high-power-density core which will provide a maximum total flux of 1 to 2×10^{15} neutrons/cm^2-sec. There will be 9 horizontal beam tubes in the reflector, 2 of them arranged to bring out double beams.

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.

The architect-engineer work is being done by the Lummus Company under contract to the Atomic Energy Commission. The reactor is being constructed on Rutherford Hill, southeast of the BGRR's cooling tower. Construction was nearing completion at the end of the fiscal year, and systems testing is expected to begin before the end of 1964.

Tandem Van de Graaff

A tandem Van de Graaff facility is in the advanced planning stage. It will consist of 2 tandem Van de Graaff accelerators arranged to be used in series as a 3-stage accelerator. The energy range for singly charged particles with the 3-stage arrangement extends from $\approx$4MeV to 30 or 40 MeV with an energy spread not greater than $\pm$2 kV.

The emphasis in the research program at this new facility will be on the study of nuclear struc-

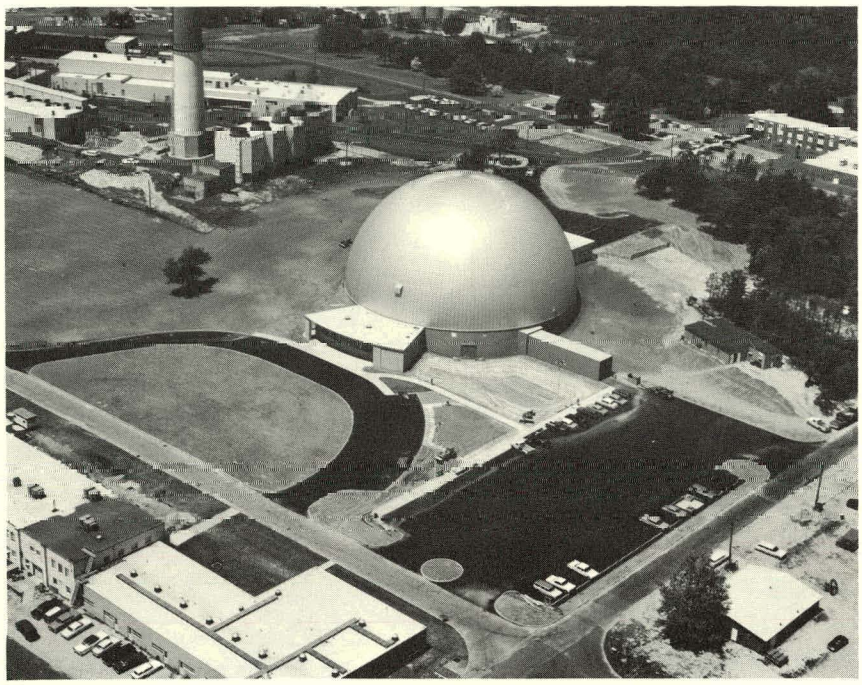


Figure 9. Aerial view of the containment vessel for the High Flux Beam Research Reactor, taken near the end of fiscal 1964. This reactor, which will begin operation in 1965, will provide intense beams of neutrons for a variety of research purposes.

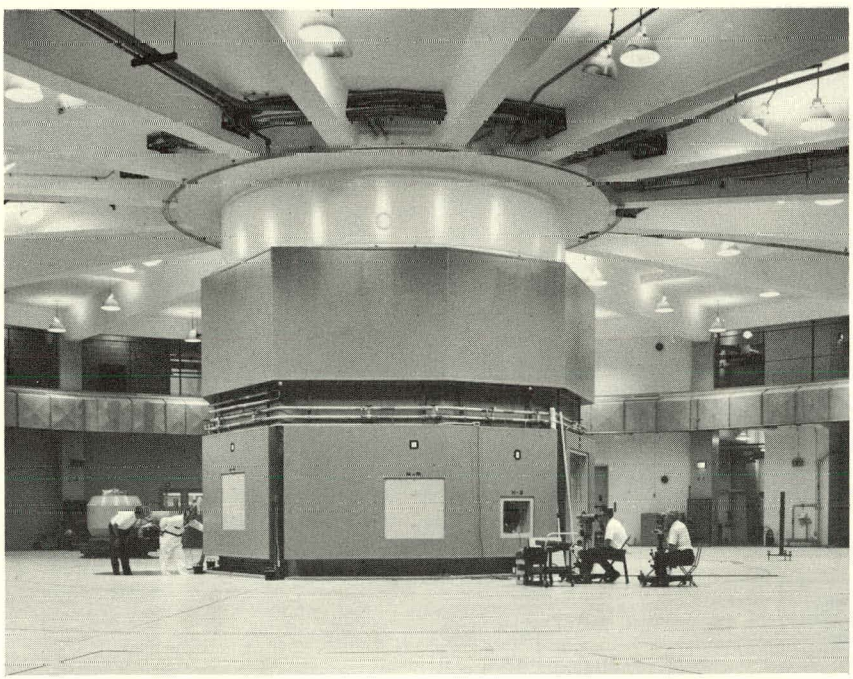


Figure 10. View of the High Flux Beam Research Reactor at the experimental floor level, showing 3 of the 9 holes for bringing intense beams of neutrons out through the shielding to experimental equipment.

Figure 11. The new Instrumentation and Health Physics Building, completed and occupied in June 1964.

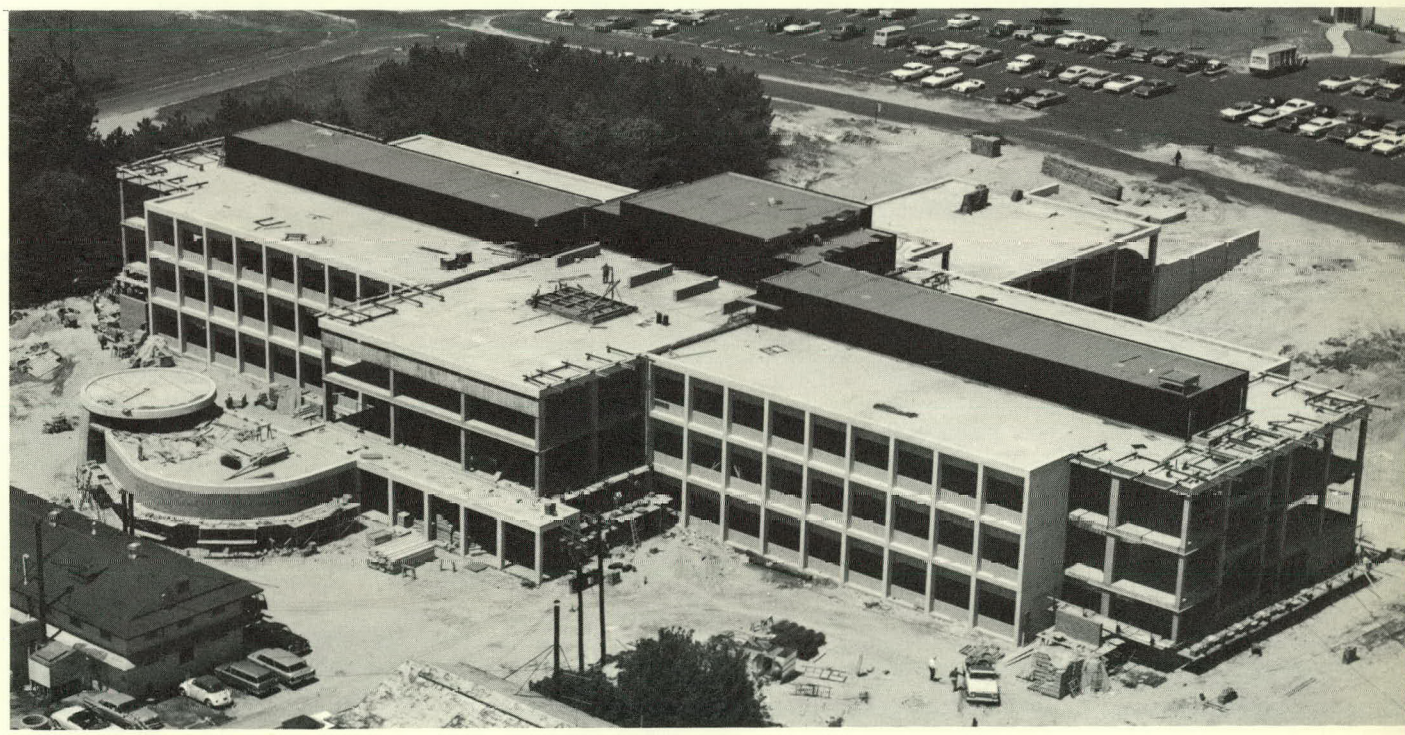


Figure 12. Aerial view (May 1964) of the new Chemistry Building, which is scheduled for completion in the summer of 1965.

ture over the whole energy range available from the 3-stage operation of the 2 accelerators. However, the arrangement of the machines is designed to allow each one to be operated separately as a 2-stage tandem Van de Graaff accelerator with energy up to 20 to 25 MeV; this will greatly extend the research capabilities of the facility.

There will be 4 experimental scattering rooms containing a total of 22 beam tubes and associated equipment. A high-resolution magnetic spectrometer is planned as one of the instruments to be used in the nuclear structure research program. Scattering chambers and other types of experimental apparatus are being designed for future application in the tandem Van de Graaff research program. Existing experimental programs at the cyclotron and the small Van de Graaff at Brookhaven will be extended into the energy region made available with the new tandem facility.

Detailed specifications were drawn up for the desired performance characteristics, and a proposal was solicited from the High Voltage Engineering Corporation for the manufacture of two tandem Van de Graaff machines and auxiliary equipment. This proposal will be evaluated and a contract negotiated.

The Catalytic Construction Company was selected as the architect-engineer for the building to house this facility. Preliminary building design is progressing according to schedule.

GENERAL CONSTRUCTION PROGRAM

As previously mentioned, construction of the Southwest Experimental Area at the AGS was completed. In addition, the new Instrumentation and Health Physics Building was completed and occupied at the end of the fiscal year. This structure, which replaces 4 temporary World War II buildings in 2 locations, provides 47,000 sq ft of space for laboratories, shops, and offices.

In September 1963 construction of a new water treatment plant was begun. In October construction began on the Physics and Mathematics addition to the Physics Building, which will provide 133,500 sq ft of floor space and is expected to be completed in the fall of 1965. During that same month construction also began on the Controlled Environment Laboratory. This 33,500-sq-ft addition to the Biology Building is scheduled for completion in the spring of 1965.

Construction continued throughout the year on the new 138,000-sq-ft Chemistry Building, scheduled to be completed in the summer of 1965.

Construction of the steam plant addition and work on the preliminary design of the tandem Van de Graaff facility are scheduled to begin early in fiscal 1965. Construction of the 4-level radiation counting facility for clinical research is scheduled to begin about midway through fiscal 1965. Also scheduled to begin in fiscal 1965, contingent upon congressional approval, is the Lecture Hall–Cafeteria.

Detailed planning continued for the laboratories and facilities required to meet Brookhaven's needs. These include the AGS Target Building and Service Building additions, the Technical Photography and Graphic Arts Building, the Hot Laboratory addition, the Central Shops Building, the Molecular Biology addition, and the HIRDL addition. Brookhaven will request a continuation of this building program for future years so that its function as a research center can be efficiently and economically fulfilled.

PERSONNEL

The total number of employees at Brookhaven National Laboratory on June 30, 1964, excluding temporary appointees, Research Collaborators, and guests, was 3065. This represents a net increase over fiscal 1963 of 155, or 5.2%. During fiscal 1964 the regular salaried scientific staff (Ph.D. or equivalent) increased from 369 to 401, Research Associates from 80 to 85,* and salaried visitors from 31 to 37,* for a total increase in the salaried staff from 480 to 523. The nonsalaried scientific staff increased from 516 in 1963 to 609 in 1964 as of May 31 of these years. The latter visitors are not at Brookhaven on a full-time basis. About one-fourth to one-third of them are on site at any given time. About 600 (as compared to 550 the previous year) visiting scientists and students (salaried and nonsalaried) worked at the Laboratory during the year; this number does not include Research Associates. These individuals were affiliated with 203 different institutions. The total number of professional employees (B.S. or equivalent) increased during the year from 297 to 323.

*These figures include students. For further details, see Tables 1 and 2 in the section on Administration and Operations.

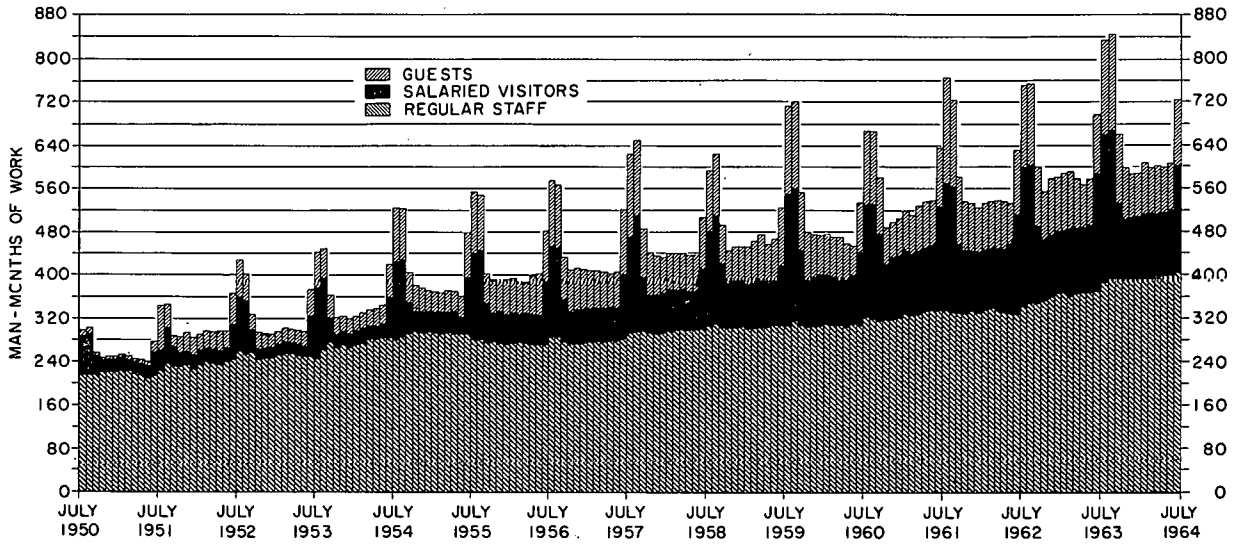
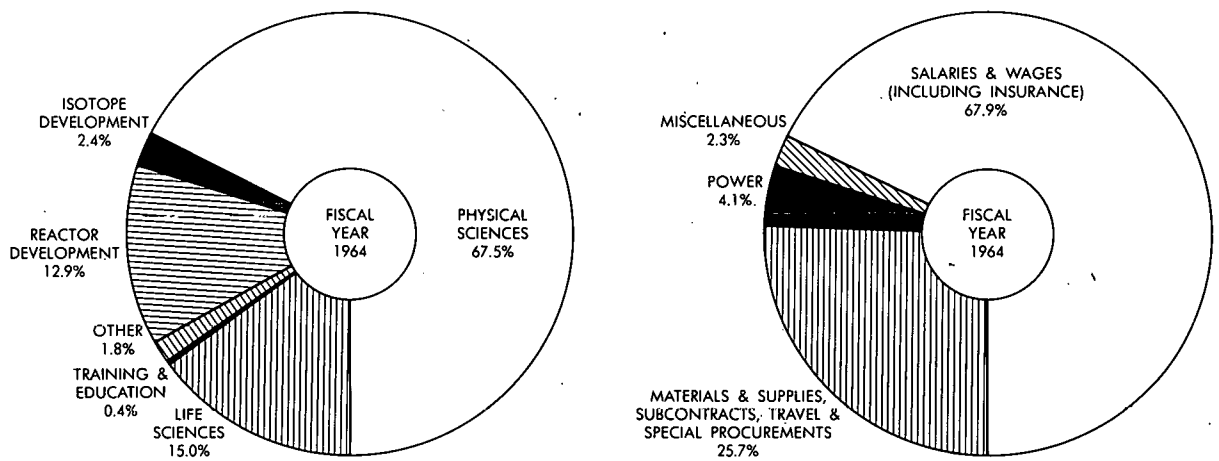


Figure 13. Scientific staff and students.



OPERATING COST DISTRIBUTION BY PROGRAMS

FISCAL YEAR	PHYSICAL SCIENCES	REACTOR DEVELOPMENT	LIFE SCIENCES	ISOTOPE DEVELOPMENT	TRAINING & EDUCATION	OTHER (NET)	TOTAL COST
1964	27,856,193	5,318,029	6,211,430	979,385	174,142	737,511	41,276,690
1963	24,291,685	4,723,994	5,776,303	964,471	135,985	1,111,563	37,004,001
1962	18,930,903	3,892,953	5,216,925	547,238	145,587	929,043	29,662,649

MAJOR CATEGORIES OF OPERATING EXPENDITURES

FISCAL YEAR	SALARIES & WAGES	MATERIALS & SUPPLIES SUBCONTRACTS, TRAVEL & SPECIAL PROCUREMENTS	POWER	MISCELLANEOUS (NET)	OPERATING TOTAL
1964	28,017,348	10,629,739	1,694,359	935,244	41,276,690
1963	24,795,398	9,522,285	1,310,258	1,376,060	37,004,001
1962	20,881,773	6,831,784	1,047,376	901,716	29,662,649

Figure 14.

Table 1

Organizational Expenditures – Fiscal 1962, 1963, 1964

(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				Sub-contracts & Special Procure-ments			Total Organi-zational Costs	% of Total	Man-Years		
		Staff	Consultants & Temporary Employees	Travel	Material & Supplies		Power	Miscel-laneous (Net)			Scientific & Professional (Incl. Guests)	Others	Total
Physics & Chemistry Research	1964	10,054,317	302,001	224,039	4,500,694	104,392	977,705	—	16,163,148	39.2	461.5	628.5	1,090.0
	1963	8,637,495	335,333	198,836	3,686,095	94,830	634,176	—	13,586,765	36.7	425.5	584.5	1,010.0
	1962	6,703,649	229,532	163,881	2,399,307	250,803	402,092	(1,000)	10,148,264	34.2	375.0	438.0	813.0
Biology, Medicine & Biophysics Research	1964	3,046,927	116,484	64,371	775,220	—	—	(111)	4,002,891	9.7	155.5	226.0	381.5
	1963	2,753,044	112,478	76,131	721,110	125	—	(1,128)	3,661,760	9.9	148.5	212.0	360.5
	1962	2,493,351	86,324	81,635	603,116	770	—	(5,303)	3,259,893	11.0	140.5	194.5	335.0
Nuclear Engineering Research	1964	2,788,603	71,227	80,476	855,197	563,009	—	—	4,358,512	10.6	130.5	141.5	272.0
	1963	2,420,259	72,127	91,592	769,155	437,859	—	—	3,790,992	10.2	118.0	141.5	259.5
	1962	2,208,169	38,870	85,757	592,567	113,116	—	—	3,038,479	10.2	113.0	129.0	242.0
Isotope Development	1964	404,902	7,632	9,045	120,246	44,444	—	—	586,269	1.4	23.5	19.5	43.0
	1963	345,204	6,570	8,356	135,446	103,935	—	—	599,511	1.6	19.5	18.0	37.5
	1962	193,727	6,897	10,165	67,888	47,119	—	—	325,796	1.1	13.5	10.5	24.0
Training & Education	1964	50,093	29,561	24,079	16,475	8,504	—	—	128,712	0.3	4.0	5.0	9.0
	1963	48,485	2,752	31,139	5,582	7,029	—	—	94,987	0.3	3.5	1.5	5.0
	1962	47,838	3,419	26,789	30,185	2,093	—	(6,800)	103,524	0.4	3.5	0.5	4.0
Radiation Protection	1964	569,289	2,321	2,943	111,436	—	—	(13)	685,976	1.7	12.0	55.5	67.5
	1963	523,807	2,201	4,412	179,110	11	—	(491)	709,050	1.9	12.5	53.0	65.5
	1962	475,329	2,258	5,677	85,619	—	—	—	568,883	1.9	3.0	47.0	50.0
Supporting Scientific & Technical Services	1964	4,912,675	28,379	35,577	777,441	747,017	252,521	(129,001)	6,624,609	16.0	78.5	443.5	522.0
	1963	4,456,791	17,931	30,827	738,555	758,812	255,073	(134,749)	6,123,240	16.5	63.0	422.5	485.5
	1962	3,607,195	22,184	26,812	1,116,269	19,470	281,880	(129,824)	4,943,986	16.7	67.0	365.5	432.5
Security & Plant Protection	1964	641,497	15	1,934	18,726	—	—	2,352	664,524	1.6	—	75.0	75.0
	1963	584,084	—	619	18,661	—	—	1,932	605,296	1.6	—	75.5	75.5
	1962	580,958	552	876	9,841	—	—	2,351	594,558	2.0	—	75.0	75.0
Miscellaneous (including Lighting, T & T, Heating Fuels, Special Maintenance, etc.)	1964	—	—	2,409	94,532	(13,936)	464,133	855,968	1,403,106	3.4	—	—	—
	1963	—	—	2,246	266,568	(11,457)	421,009	937,805	1,616,172	4.4	—	—	—
	1962	—	—	908	183,800	(8,827)	363,404	838,735	1,378,020	4.6	—	—	—
General and Administrative	1964	4,907,509	57,778	150,206	1,229,515	(704)	—	(268,951)	6,075,353	14.7	42.5	624.5	667.0
	1963	4,357,676	55,716	89,366	870,938	21,757	—	97,690	5,493,143	14.9	37.0	576.5	613.5
	1962	4,053,265	51,371	151,104	572,470	15,200	—	(27,123)	4,816,287	16.2	—	563.5	563.5
Laboratory Total	1964	27,375,812	615,398	595,079	8,499,482	1,452,726	1,694,359	460,244	40,693,100	98.6	908.0	2,219.0	3,127.0
	1963	24,126,845	605,108	533,524	7,391,220	1,412,901	1,310,258	901,060	36,280,916	98.0	827.5	2,085.0	2,912.5
	1962	20,363,481	441,407	553,604	5,661,062	439,744	1,047,376	671,016	29,177,690	98.3	715.5	1,823.5	2,539.0
AUI Administration	1964	—	—	—	—	—	—	475,000	475,000	1.1	—	—	—
	1963	—	—	—	—	—	—	475,000	475,000	1.3	—	—	—
	1962	—	—	—	—	—	—	230,700	230,700	0.8	—	—	—
Total AUI and BNL	1964	27,375,812	615,398	595,079	8,499,482	1,452,726	1,694,359	935,244	41,168,100	99.7	908.0	2,219.0	3,127.0
	1963	24,126,845	605,108	533,524	7,391,220	1,412,901	1,310,258	1,376,060	36,755,916	99.3	827.5	2,085.0	2,912.5
	1962	20,363,481	441,407	553,604	5,661,062	439,744	1,047,376	901,716	29,408,390	99.1	715.5	1,823.5	2,539.0
Work for Others, Direct Costs Only	1964	26,138	—	7,206	33,033	42,213	—	—	108,590	0.3	3.0	4.0	7.0
	1963	63,409	36	11,501	152,217	20,922	—	—	248,085	0.7	8.5	5.0	13.5
	1962	75,079	1,806	4,015	111,789	61,570	—	—	254,259	0.9	7.5	7.5	15.0
Grand Total	1964	27,401,950	615,398	602,285	8,532,515	1,494,939	1,694,359	935,244	41,276,690*	100.0	911.0	2,223.0	3,134.0
	1963	24,190,254	605,144	545,025	7,543,437	1,433,823	1,310,258	1,376,060	37,004,001**	100.0	836.0	2,090.0	2,926.0
	1962	20,438,560	443,213	557,619	5,772,851	501,314	1,047,376	901,716	29,662,649†	100.0	723.0	1,831.0	2,554.0

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

**$925,374 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

†$712,038 of this total was distributed to Fixed Assets and as services to Work for Others and Inventory.

Table 2

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

	Fiscal 1964		Fiscal 1963		Fiscal 1962	
	$	%	$	%	$	%
Scientific & hospital	6,728,208	95.0	10,021,696	95.2	6,604,023	93.6
Automotive & heavy mobile	91,295	1.3	195,927	1.9	154,852	2.2
Office machines & furniture	105,019	1.5	125,626	1.2	87,252	1.2
Shop equipment	109,509	1.5	134,232	1.3	159,313	2.3
Miscellaneous	49,988	0.7	39,843	0.4	46,661	0.7
Expenditures, Total	7,084,019	100.0	10,517,324	100.0	7,052,101	100.0
Proceeds from sales	(32,386)		(63,770)		(12,665)	
Expenditures, Net	7,051,633		10,453,554		7,039,436	

Table 3

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

	Fiscal 1964			Fiscal 1963			Fiscal 1962		
		Man-years			Man-years			Man-years	
	Costs, $	Sci.	Others	Costs, $	Sci.	Others	Costs, $	Sci.	Others
Alternating Gradient Synchrotron									
Direct									
Salaries, wages, insurance	—	—	—	—	—	—	—	—	—
Materials, construction, etc.	74,607			245,413			1,226,016		
Subtotal direct	74,607			245,413			1,226,016		
Charges from organizational units	—			29,894			22,231		
Total	74,607			275,307			1,248,247		
Other, Including High Flux Beam Research Reactor and 80-in. Bubble Chamber									
Direct									
Salaries, wages, insurance	600,399	20.5	33.0	557,471	21.0	29.0	776,466	32.5	49.5
Materials, construction, etc.	9,290,045			14,178,652			10,079,560		
Subtotal direct	9,890,444			14,736,123			10,856,026		
Charges from organizational units	479,700			635,402			476,206		
Total	10,370,144			15,371,525			11,332,232		

Table 4

Inventory at Close of Fiscal Year

Type of inventory	Fiscal year		
	1964	1963	1962
General stores*	$ 618,905	$ 781,849	$ 704,424
Precious metals and radium	206,089	137,745	96,683
Stable isotopes	51,962	32,899	38,793
Heavy water	753,685	674,252	683,039
Total	$1,630,641	$1,626,745	$1,522,939

*The number of months investment was 2.2 in 1964, 3.0 in 1963, and 3.5 in 1962.

Summer visitors continue to play a significant role in the Laboratory's program. Arrangements have been made for 304 visiting scientists and students to work at Brookhaven during the summer of 1964. Of this number, 140 are staff members from various educational and research institutions, and 164 are students.

ADMINISTRATION

The organization of the Laboratory, as of July 1964, is given in Figure 1. At their annual meeting in October 1963 the AUI Board of Trustees made five appointments. Mr. LaRoy B. Thompson, Vice President of the University of Rochester, succeeded Dr. I.I. Rabi of Columbia University as Chairman of the Board; Mr. Edward Reynolds, formerly Administrative Vice President of Harvard University, was re-elected President of the corporation (Mr. Reynolds had served in that capacity since last July when Dr. Gerald F. Tape resigned to accept a White House appointment to the U.S. Atomic Energy Commission); and three new members were elected to the AUI Board of Trustees: Dr. Franklin A. Long and Dr. Boyce D. McDaniel of Cornell University, for terms expiring in October 1965 and 1966, respectively; and Dr. Richard H. Chamberlain of the University of Pennsylvania, whose term will expire in October 1964.

Effective July 1, 1964, Dr. William J. Catacosinos was appointed an Assistant Director with principal responsibilities in the areas of business management and business administration. Dr. Catacosinos had been Business Manager of the Laboratory.

FINANCE

AEC-supported research at the Laboratory continued to be financed by the AEC Divisions of Reactor Development, Research (Physical Sciences), Biology and Medicine (Life Sciences), Training and Education, and Isotope Development. Operating costs for the work in each program and the major categories of operating expenditures are shown in Figure 14. Details of the operating expenditures of the Laboratory on a broad operational basis are given in Table 1.

Table 2 shows expenditures for capital equipment, Table 3 is a summary of expenditures for fixed assets (plant and equipment), and Table 4 reflects inventories for which the Laboratory is responsible.

BROOKHAVEN NATIONAL LABORATORY

COMPARATIVE BALANCE SHEET

	June 30, 1964	June 30, 1963
Assets		
Cash	$ 566,351	$ 1,433,405
Accounts receivable	234,874	271,039
Advances and prepaid expenses	74,149	146,902
Deposits	89,816	88,605
Property, plant, and equipment (less reserves of $50,444,057 at June 30, 1964, and $44,470,532 at June 30, 1963)	125,254,054	113,987,322
Research materials and supplies	11,630,408	6,987,689
Total assets	$137,849,652	$122,914,962
Liabilities		
Accounts payable	$ 3,658,824	$ 4,358,184
Accrued vacations	2,269,901	2,009,541
Accrued payroll	316,904	205,571
Atomic Energy Commission	131,604,023	116,341,666
Total liabilities	$137,849,652	$122,914,962

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

CONFERENCES

Six formal conferences were held at the Laboratory during the fiscal year. One of them, the Symposium on Biological Effects of Neutron Irradiations, October 7-11, was the first meeting sponsored by the International Atomic Energy Agency to be held in the United States. It was attended by $\approx$150 scientists representing 19 countries and 4 international agencies. Other conferences were as follows: Fundamental Aspects of Weak Interactions, September 9-11; Evaluated Nuclear Data Files Meeting, May 4-5; National Research Council Solid State Sciences Advisory Panel, May 11-12; AEC Meteorological Activities Conference, May 19-21; and Biology Symposium No. 17, entitled "Subunit Structure of Proteins," June 1-3.

Figure 15. Dr. Henry Seligman (center), Deputy Director of the International Atomic Energy Agency (IAEA), delivering the opening address at the Symposium on Biological Effects of Neutron Irradiations, held at Brookhaven National Laboratory from October 7 through 11, 1963. At the speakers' table with Dr. Seligman are the two IAEA Scientific Secretaries for the symposium, Dr. Vladimir Zeleny (far left) and Mr. Evgenii Komorov (far right). On Dr. Seligman's right is Dr. Maurice Goldhaber, Director of Brookhaven National Laboratory, and on his left is Dr. Harold H. Smith, of the Laboratory's Biology Department. This was the first scientific symposium to be held in the United States under the sponsorship of the IAEA, a United Nations-affiliated organization with headquarters in Vienna. Approximately 150 scientists from 19 countries attended the symposium.

PHYSICAL SCIENCES AND ENGINEERING

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Physics

The physics research program consists of experimental and theoretical studies concerned with the structure and fundamental properties of matter. Various features of the complex structure and properties of matter can be most effectively studied by observing the interactions of charged particles, neutral particles, and radiation with matter. Some of these studies deal with the interactions involving individual atoms, atomic nuclei, or nucleons, and others with conglomerates of atoms and molecules in bulk matter. The Alternating Gradient Synchrotron, Cosmotron, 60-in. cyclotron, Van de Graaff accelerator, 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 augmented by that of a number of visiting and guest scientists on leave from other institutions in this country and abroad. These visitors and guests are attracted to Brookhaven not only by the availability of its facilities but also by the opportunity to collaborate with Brookhaven scientists. The interchange of ideas and experience resulting from the presence of these visiting scientists is very important to an active research program.

PARTICLE PHYSICS

The number of universities and laboratories sharing in the particle physics research at Brookhaven National Laboratory clearly demonstrates its national nature. About two-thirds of the work at the Alternating Gradient Synchrotron (AGS) and the Cosmotron is done by groups from these organizations. During fiscal 1964 more than 370 guest scientists participated in the program, including representatives of all the AUI institutions:

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

The following organizations were also represented:

Brandeis University
Brown University
California Institute of Technology
Carnegie Institute of Technology
City University of New York
Duke University
Florida State University
Institute for Advanced Study
Iowa State University
Naval Research Laboratory
Northwestern University
Oak Ridge National Laboratory
Ohio University
Rensselaer Polytechnic Institute
Rockefeller Institute
Rutgers University
Stanford University
State University of New York
Syracuse University
University of California at Berkeley
University of California at La Jolla
University of Colorado
University of Illinois
University of Indiana
University of Maryland
University of Miami
University of Michigan
University of Tennessee
University of Washington
University of Wisconsin
Vanderbilt University

Guest scientists also included representatives of the following foreign laboratories : AERE, Harwell, England; AERI, Seoul, Korea; Cambridge University, England; CERN, Geneva, Switzerland; École Polytechnique, Paris, France; Imperial College, London, England; Middle East Technical University, Ankara, Turkey; Pisa University, Italy; University of Delhi, India; University of Rome, Italy; and Woodstock College, England.

No attempt has been made to cover all the work accomplished at BNL in particle physics during

the past fiscal year. A detailed list of publications in the field is included in Appendix A. The material that follows presents the highlights and a typical cross section of the research activity for this period.

General

Presently known fundamental interactions in nature are the result of four types of force – gravitational, electromagnetic, weak, and strong. Both the weak (weak interaction) and the strong (strong or nuclear interaction) forces are associated with the behavior and constitution of the nucleus and the fundamental particles. Weak interaction forces ($\approx 10^{-13}$ times as weak as nuclear forces) are responsible for the slow ($\gtrsim 10^{-10}$-sec) decay of particles and the β decay of the nucleus. In contrast, the strong interactions must be invoked to explain other nuclear and particle interactions such as scattering and particle production. Although the interactions of the fundamental particles depend on the exact forces involved, these forces are subject to general restrictions, the conservation laws and invariance principles, some of whose consequences are independent of the detailed description of the forces.

Some of these laws, such as the conservation of energy and momentum, seem comprehensible to us because of their familiarity. The law of conservation of charge is also familiar, but it governs an intrinsic property of particles rather than the properties of their motion. It has its basis in the quantum mechanical concepts of physics.

Other new conservation laws revealed in particle physics appear to have equal validity but seem very peculiar because their relation to the familiar space-time properties of our world of experience is quite unknown. The concept of strangeness is one of these. Strangeness conservation can be used to provide the rules governing the experimental observation that certain of the recently discovered particles never appear as a result of nuclear collisions unless they are produced in restricted combinations in association with each other (associated production). Nucleons and π mesons, which are not produced by associated production, have strangeness quantum number equal to zero, whereas hyperons and K mesons have strangeness quantum numbers different from zero. Violation of strangeness conservation means that the process proceeds via a weak interaction with a change of strangeness ($\Delta S = 1$).

A conservation law which holds only for strong interactions is that of isospin (isotopic spin). It is an expression of a fundamental symmetry in nature whereby the interaction is independent of charge. Observations from p-p, n-n, and n-p scattering have shown that the neutron and the proton behave in a very similar way in strong interactions. In these interactions the proton and neutron may be treated formally as a single entity with two different charge states, 0 or +1, forming a doublet. The strongly interacting particles all seem to fall into multiplets, the members of such a multiplet being almost identical except for their electric charges. The particles of a multiplet with $2I+1$ components are said to have isospin I, in the same way that a particle with $2S+1$ independent polarization states has spin S. Just as a system of several particles can be assigned a total spin depending on the individual spins and polarizations, so a total isospin can be assigned depending in the same way on the individual isospins and charges, and in any strong interaction the conservation law says that this total isospin must be conserved.

Another conservation law, which embodies an as yet unknown symmetry principle, is the conservation of leptons and baryons. The baryons are all the strongly interacting particles except the mesons. The leptons are the muons, electrons, and neutrinos. This conservation law holds for all types of interaction. Whenever a baryon disappears in an interaction, another baryon must appear to take its place, or an antibaryon must also disappear. The same holds true for leptons.

The conservation of parity is a law founded on invariance under space inversion. This is a condition of symmetry such that the mirror image of an event delineates an event which is also physically possible. Parity invariance holds for the strong and electromagnetic but not the weak interactions.

The principle of time reversal invariance is an expression of an underlying symmetry in time. Time reversal invariance means, for example, that if the sequence of events in an interaction is physically possible, then the inverted sequence of events must also be possible.

The principle of invariance under charge conjugation governs the interchange of particles and antiparticles. Invariance under charge conjugation means that transformation of all the particles in any event into antiparticles also results in a physically possible event.

Parity (P), time reversal (T), and charge conjugation (C) are related mathematically in such a way that if two of them hold or do not hold for a given interaction, the third must always hold or not hold.

These conservation laws and invariance principles provide the underlying structure that makes it possible to describe and predict some of the experimental observations in particle physics. Although many of them appear to be deeply fundamental and firmly established, they must nevertheless be tested in new situations to prove their general validity.

Research at the Cosmotron

The varied program at the Cosmotron reflects the fertility of ideas brought to bear on the problems of particle physics. Such a program results from the diverse approach of the many independent university groups who avail themselves of the high energy facilities at Brookhaven National Laboratory.

The reaction $p+p \rightarrow d+\pi^+$ occurs with a small cross section for incident proton energies in the BeV range. It is, however, a fundamental reaction and of particular interest because the process of forming a deuteron from a fast-moving nucleon and a slow-moving one involves a large momentum transfer to the π meson. Interactions that occur with large cross sections, and for this reason are the ones most frequently studied, involve small momentum transfers. The reaction $p+p \rightarrow d+\pi^+$ thus represents investigation of a little explored area. It is also one of the few 2-body re-

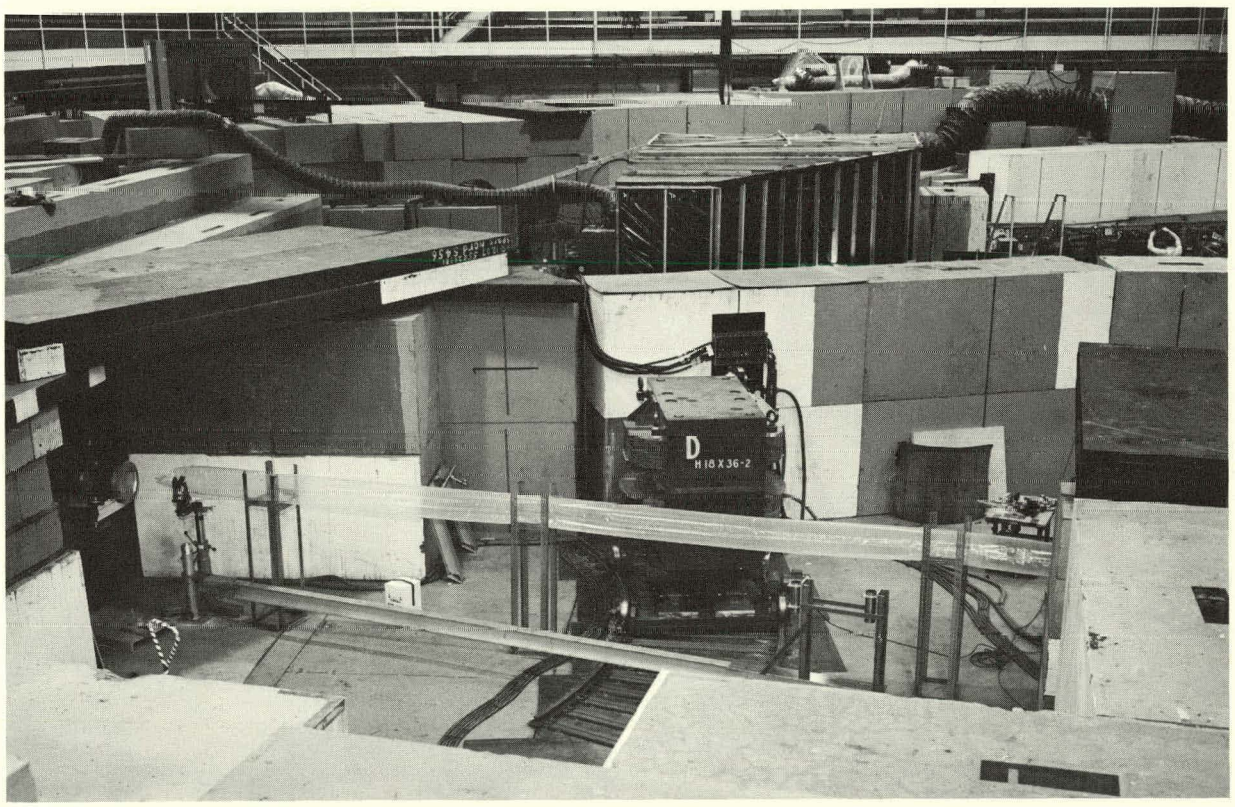


Figure 1. Experimental equipment for the study of the reaction $p+p \rightarrow d+\pi^+$. The Cosmotron external proton beam emerged from the 12-in. pipe at left. The interaction took place in a liquid hydrogen target occupying the position of the transit in the photograph. The magnet mounted on rails (center) could easily be positioned at varying angles to analyze the momentum of the deuteron. The π meson was detected by a counter telescope (not shown) mounted on the I-beam, which pivoted about the center post at the target location to set the desired angles. The nonreacting portion of the proton beam continued through the polyethylene bag (filled with helium to reduce subsequent scattering) and was absorbed by the concrete and steel beam stopper shown at the right.

actions in high energy particle physics and therefore might provide both the stimulus and tests for dynamical theories of particle interactions. Two experiments based on this reaction were performed at the Cosmotron using counters and the time-of-flight technique to identify the deuterons. A Brookhaven group measured the energy spectra of the deuteron produced at 0°. The production cross section at 0° was found to increase as the incident proton energy increased from 1.3 to 2.5 BeV. Shortly after this result was obtained a group at CERN observed that the production at close to 0° decreased as the incident proton energy was increased from 3 to 10 BeV. Together these two experiments show that a peak in the production process at 0° exists at $\approx$2.5-BeV incident proton energy. A satisfactory explanation of this peak has been made in terms of a one-pion exchange (OPE) involving the π^+-p resonance with isospin $I=3/2$ and total angular momentum $J=1/2$, a nucleon isobar (excited state). If this interpretation is confirmed by future experiments, it will represent a surprising success for the OPE model, whose application is supposed to be limited to small momentum transfer processes.

Another group from Michigan and Stanford measured the differential cross section in about the same energy range as that used in the Brookhaven work. To cover all angles of interest the deuteron momentum analyzing magnet was mounted on rails (see Figure 1) and could be easily positioned to accept deuterons throughout the range from 0° to 25°. They were able to conclude that the peak deduced above was caused by the energy dependence of the angular distribution rather than being indicative of any maximum in the total cross section. Values for the total cross section were derived from differential cross section measurements. It was further pointed out that their data seemed to suggest a peripheral interaction.

This same group is extending its work to study multipion resonances including the ζ, ρ, and X^0 mesons. Since the experimental situation concerning the existence of a π-π resonance at 560 MeV, the so-called ζ particle, is unresolved, the good statistics available from this counter experiment may provide a definite answer. The apparatus being used includes a comprehensive system of γ-ray conversion spark chambers which make it possible to study the decay modes of the resonances.

A group from Princeton University, using a spark chamber and magnet spectrometer setup very similar to that for their neutral K-meson experiment at the AGS (described below), searched for the 2-π decay of the ω meson. Their work was mainly restricted to low momentum transfer events (90%$<$400 MeV/c), but they found no evidence for this mode of decay. This result indicated that more work is needed to definitively establish the 2-pion state of the ω reported last year.

A team from Brandeis, Brown, Harvard, MIT, and Padua has used spark chambers to study two phenomena: (1) the simple charge exchange process $\pi^- + p \rightarrow \pi^0 + n$ in the neighborhood of the second (1.52-BeV) and third (1.68-BeV) nucleon resonances, and (2) the production of the η_0 meson by the process $\pi^- + p \rightarrow \eta_0 + p$. In these experiments γ rays from decaying π^0 and η_0 mesons were detected by conversion in a steel spark chamber surrounding a hydrogen target, and the γ-ray kinematic properties were used to separate the π^0 from the η_0 production processes.

Angular distribution for the charge exchange process near the third nucleon resonance showed asymmetries supporting the assignment of $F_{5/2}$ (orbital angular momentum $L=3$, total angular momentum $J=5/2$) to this state with $I=1/2$ consistent with dispersion theory predictions. No significant asymmetries were observed near the second nucleon resonance.

It has been noted for some time that the sum of the masses $\eta_0 + n = 1.48$ BeV is very close to the total energy of the second nucleon resonance $N^* = 1.52$ BeV. Part two of this experiment dealt with the possible relationship between the production of the η_0 meson and this second nucleon resonance. The observed angular distribution for the production of η_0's is quite isotropic from the threshold energy up to 1 BeV, and the increase in cross section, which was found to be nearly linear with energy in the center-of-mass system, suggests a $S_{1/2}$ or $P_{1/2}$ production state in contrast to a $D_{3/2}$ state believed to be characteristic of the second nuclear level. It thus appears that the excitation of the second nuclear level is not related to the production of the η_0 mesons.

The $\Delta I = 1/2$ rule is a selection rule connected with the change of isospin in the weak decays of strange particles. A theory involving simple assumptions about the structure of the Lagrangian predicts this rule in the leptonic decays of the K meson. The validity of this rule in the nonleptonic decays is well established experimentally, and the rule gives a unique prediction for the ratio of decay

of the K^+ and the K_2^0 mesons into leptons. Relations between the various modes of decay of the K^0 and K^+ mesons, which had already been experimentally established, revealed that the only missing piece of experimental information needed to test the rule was the ratio of the K_2^0 to the K_1^0 decays of the K^0 meson. An experiment to measure this ratio was carried out by a group from the University of Pennsylvania. Neutral K mesons were produced in the reaction $\pi^- + p \rightarrow \Lambda + K^0$ by using 1-BeV/c pions from the Cosmotron incident on a liquid hydrogen target. The K mesons and Λ hyperons were observed to decay in a thin-plate spark chamber triggered by a scintillation counter system. The measured directions of the incident pion and of the four charge decay products permit the overdetermined reconstruction of events that involved the production of a Λ and a K^0 in the hydrogen target and the subsequent 2-body decay of a Λ. Analysis of the corresponding kaon decays leads to identification of events that are consistent with the 2-body decay of the K_1^0, and of events that are inconsistent with the 2-body decay mode. Events recognized as 2-body kaon decays yielded a lifetime in good agreement with the known lifetime of the K_1^0. Events selected as non-2-body decay, which were identified as K_2^0 decays, were observed to be distributed uniformly in time, as would be expected for these long-lived ($\approx 10^{-8}$-sec) particles. After appropriate corrections for counter geometry and arbitrary limitations of event selection criteria due to experimental design, the measured ratio of K_2^0 to K_1^0 decays established that the $\Delta I = \frac{1}{2}$ rule holds for leptonic decays within the error of measurement.

The sharply peaked forward n-p charge exchange cross section provides a convenient mechanism for producing monoenergetic beams of neutrons at high energy accelerators. The neutron beam produced in the forward direction is monoenergetic in the sense that it consists of a sharp peak in intensity at an energy corresponding to the full energy of the circulating protons, and this peak is well separated in energy (≈ 150 MeV) from the neutrons associated with pion production. This method of producing a monoenergetic neutron beam has become particularly attractive at the Cosmotron because the previously observed neutron energy spread, resulting mainly from the beam spill time, has been eliminated by flat-topping the magnetic field of the machine. For a solid angle of 1.6×10^{-5} steradians a flux of charge exchange neutrons of $\approx 10^5$ neutrons/pulse is obtained. This flux produces a counting rate in the detector system of ≈ 3000 counts/hr. The observed width of the peak is within experimental error equal to the energy resolution of the counter, 40 MeV at 2.2 BeV. The ratio of charge exchange to inelastic protons was found to be 0.1 at 2.2 BeV and 0.06 at 2.8 BeV.

Previous determination of n-p total cross sections in the BeV region had to be derived from p-p and p-d total cross section measurements. The new "monoenergetic" neutron beam at the Cosmotron now makes it possible to carry out direct measurements. Using this technique, a BNL counter group has measured the n-p total cross section from 0.7 to 2.8 BeV with the full width at half-maximum of the incident neutron beam of <40 MeV at 2.2 BeV. The results are in excellent agreement with the derived values. It was possible to conclude that within experimental error charge symmetry holds in nucleon-nucleon interactions in this energy region.

The classical concept of the electric current carried by a particle can be carried over into a quantum mechanical description and represents the potential ability of the particle or system to emit and absorb electromagnetic radiation. The electronic charge e is a "coupling constant" representing the inherent strength of the interaction of the field with matter, while the current also takes account of the availability of matter with which the field can interact. Electromagnetic interactions are therefore determined by the structure of electromagnetic currents present. Weak interactions such as the β-decay interaction can be described in terms of similar quantities called weak currents, a major difference being that there are now two distinct types called vector and axial vector currents, whereas the electromagnetic currents are only of the vector type. These two types of weak currents associated with some system represent its propensity for participating in weak interactions of the vector and axial vector type. The corresponding coupling constants are the analogues of the electronic charge, for the two types.

An experiment to study the rare β decay of the Λ ($\Lambda \rightarrow p + e^- + \nu$) has been performed at the Cosmotron. Its purpose was to determine the vector and axial vector coupling constants in the decay interaction and observe their momentum dependence, if it exists. The slow decays of strange particles have led to the speculation that the decay

mechanism must be similar to that described by the Fermi theory for β decay. Attempts have thus been made to explain the decay of strange particles on the basis of a universal theory which would be identical for both the strange particles and ordinary β decays of the neutron (or nuclei). It is fortunate that Λ's are produced in a highly polarized state from the reaction $\pi^- + p \rightarrow \Lambda + K^0$. Theory shows that this results in an asymmetry in the angular distribution of the decay products which varies with the strength of the vector or axial vector currents controlling the decay interaction. Approximately 1-BeV π^- mesons incident on a liquid hydrogen target produced the polarized Λ's. The Λ's, the associated K^0's and the Λ-decay products were identified by a system of spark chambers, scintillation counters, and a large threshold Cerenkov counter of unusual design. The Cerenkov counter was a high-pressure vessel $\approx$8 ft in diameter containing a spherical mirror for light collection. It was located so that the Λ decays occurred in the region of the focus of the spherical mirror. This technique greatly increased the number of electrons that could be detected. The counter was filled with sulfurhexafluoride at 10 atmospheres in order to count electrons and reject π mesons. It thus served to signal the occurrence of a β decay and triggered the cameras recording the event. Since the Λ decays into a proton and a π^- meson two-thirds of the time, these unwanted events would not trigger the system. About one-third of the Λ's decay into a proton and a π^0 meson, and these, together with a π^0 meson from the K^0 decay, have a decay scheme that finally results in electrons which can produce large numbers of false triggers. However, these are easily detected when the photographs are scanned, and such events are rejected. The data-taking for this experiment has been completed and the analysis is in process.

A special beam has been designed at the Cosmotron which has been split in such a way as to permit two studies of the K meson to be carried out simultaneously. A Maryland-BNL team is studying the decay of stopped K mesons produced when the primary proton beam strikes a copper target. The angular distribution of electrons emitted in the muon decay is measured in spark chambers allowing the determination of the muon polarization. This polarization is a sensitive indicator of the type of interaction involved in the decay and is of considerable theoretical interest, since the present data on the $K_\mu{}^3$ decay are not consistent with current theory. A Columbia-Wisconsin group is using a different approach to throw light on the same problem. They are studying the lepton momentum spectra in $K_e{}^3$ and $K_\mu{}^3$ decays by using spark chambers and counters. The shapes of these spectra should also provide a determination of the form of the weak interaction responsible for the decay modes. A further result of the experiment will be a new limit on the ratio $K_e{}^2/K_\mu{}^2$ at least two orders of magnitude below the current experimental result.

The BNL 14-in. liquid hydrogen bubble chamber has been put back into service by a Yale-Brookhaven group which is investigating the interactions and decays of $K_2{}^0$ mesons and in particular is making a further study of the anomalous coherent production of $K_1{}^0$ mesons from the $K_2{}^0$ beam (see below, under the heading "Research at the Alternating Gradient Synchrotron"), about which at present there is conflicting experimental evidence. It will also be possible to study the absolute and relative transition probabilities for various $K_2{}^0$ charged decay modes and the characteristics of the decay spectra.

A group from the University of Washington is using the reaction $\pi^- + d \rightarrow \Sigma^- + n + K^+$ to search for a bound state of the Σ^--n system by measuring the energy spectra of the K^+ mesons. The Σ^--n would be the "deuteron" of strange particle physics. $SU(3)$ theory (see below) makes it possible to calculate the mass value that should be expected for this hyperdeuteron.

The detailed analysis of the data from the experiment to measure the magnetic moment of the Λ reported last year is almost complete, but no results are available as yet.

Research at the Alternating Gradient Synchrotron

Two important discoveries highlighted the research at the AGS. They illustrate the indispensability of high energy accelerators and the importance of different experimental techniques. One of the experiments involved used counters and spark chambers. The other was one of the first experiments in which the new Brookhaven 80-in. bubble chamber was used.

An elegant experiment with a surprising and important result was carried out at the AGS by a group from Princeton University. The apparatus was set up to study the decay of the neutral K

meson. As observed in the laboratory, this meson exists in two forms, called K_1^0 and K_2^0, which differ from one another in life time, in decay modes, and only very slightly in mass. The K_1^0 decays so quickly that it travels only inches before changing into two π mesons. The K_2^0 has a longer life and travels tens of meters before decaying, usually into three particles. A remarkable feature of this particle complex is that a K_2^0 may be converted into a K_1^0 in passing through matter. This process is called regeneration.

The K^0 mesons were produced by bombarding a beryllium target with the internal proton beam of the AGS. Very little equipment was needed to establish the required neutral beam. A 4-ft-long lead collimator, 14½ ft from the internal target, defined the secondary beam at 30° relative to the circulating protons just before it entered a strong magnetic field which swept out the charged particles. Thus only neutral particles entered the second beam-defining collimator (shown at the left in Figure 2) just in front of the detecting apparatus. A slab of lead 1.5 in. thick blocked the entrance to the first collimator, which reduced the flux of γ rays in the beam to an acceptable level. Just beyond the second collimator, 50 ft from the internal target, a bag containing helium enclosed the region of K^0 decays which could be detected by the spectrometer array. At this distance from the source of production (300 decay lengths) the short-lived K_1^0's had decayed out of the secondary beam. Thus, except for any regenerated K_1^0 mesons, the beam consisted only of the long-lived K_2^0 mesons and neutrons. The latter proceeded through

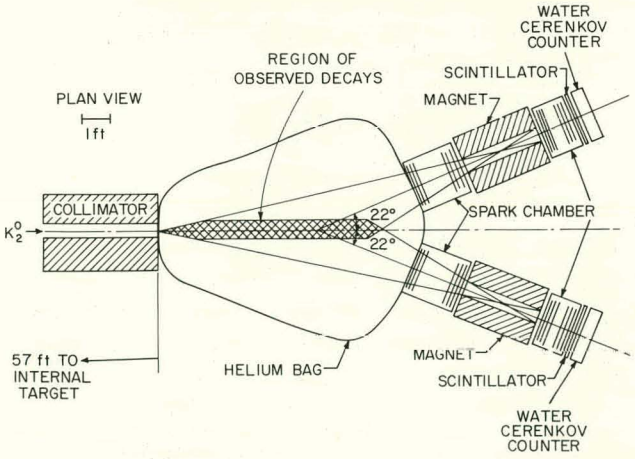


Figure 2. Plan view of the detector arrangement for the experiment to study the decay of the neutral K meson.

the apparatus along the beam line between the spectrometer magnets, producing negligible background effects. The regeneration of the K_1^0 in the detection region would be quite small even with air present, but with helium it was negligible. The magnets situated on each side of the beam line, together with the spark chambers before and after them (Figures 2 and 3), served as spectrometers to measure the momentum and the angles of the charged decay products. Tracks in these chambers were photographed when the system was triggered by the simultaneous passage of a charged particle through each of the spectrometers. This trigger was provided by a 4-fold coincidence pulse between the Cerenkov counters and scintillators positioned immediately behind the spectrometers. The Cerenkov counters were of the "threshold" type and thus gave pulses only for particles traveling at a speed equal to or greater than a given value. This value was chosen such that the counters responded to π mesons in the required momentum range. The preceding scintillation counters added the requirement that most of the particles seen by the Cerenkov counters came through the spectrometer from the direction of the decay region. Chance coincidences arising from electron-positron pair production by γ-ray conversion could masquerade as π mesons and give false triggers. However, as pointed out above, most of the γ rays were effectively blocked out of the beam. Spurious events photographed because of false triggers could in any case be rejected by the data analysis.

Prior to this experiment, the K_2^0 was thought to decay only by a 3-body mode

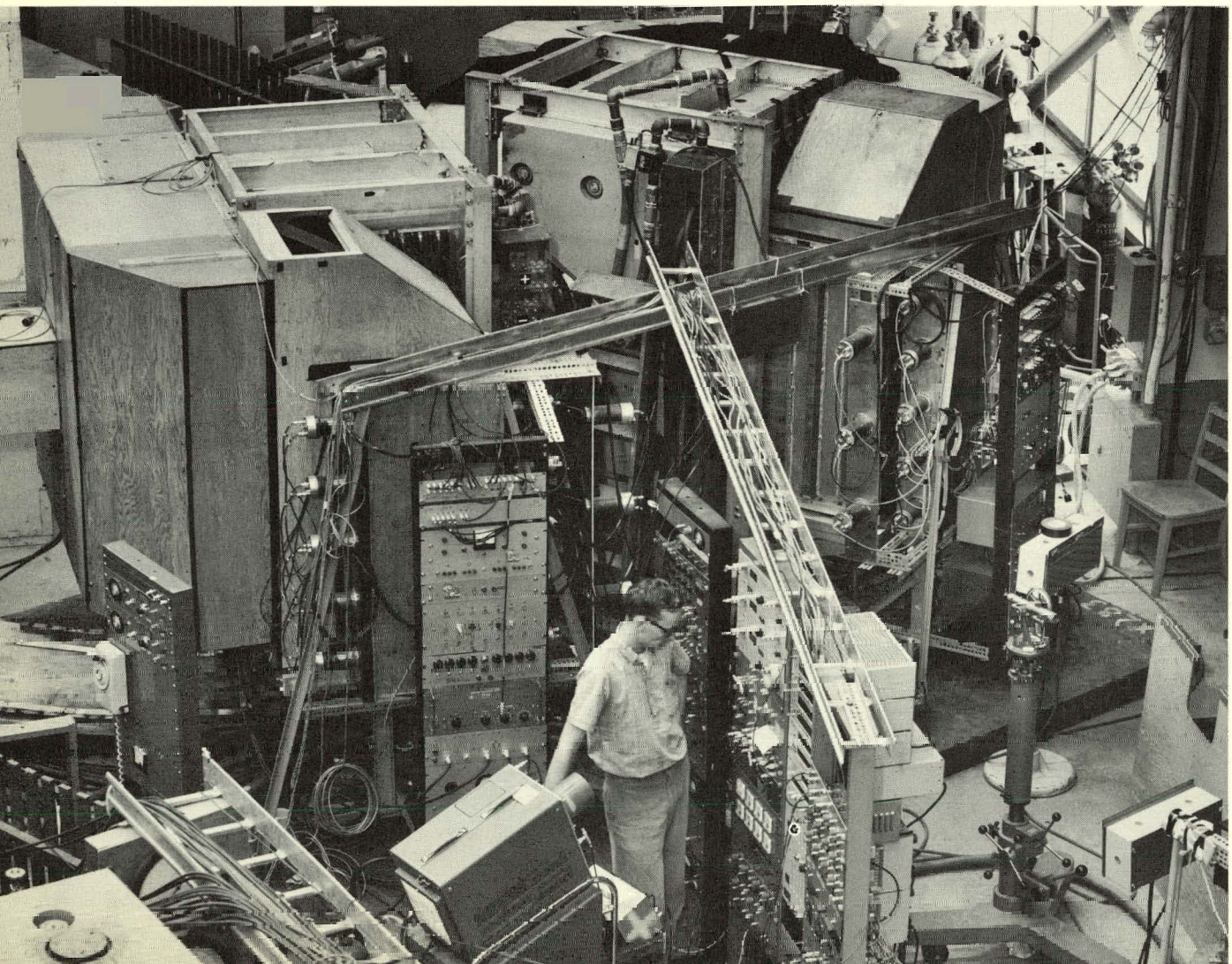
$$\begin{aligned} K_2^0 &\rightarrow \pi+\pi+\pi \\ &\rightarrow \pi+\mu+\nu \\ &\rightarrow \pi+e+\nu \end{aligned}$$

whereas the K_1^0 nearly always decays into two π mesons. In contrast, decay of the K_2^0 into two π mesons was forbidden by a fundamental principle of physics, CP (charge conjugation, parity) invariance. By inserting a piece of dense metal in the helium bag in the region of K^0 decay, it was possible to regenerate K_1^0 mesons which then quickly decayed into two π mesons. Since a K_1^0 produced by coherent regeneration has the same momentum and direction as the K_2^0 beam, the K_1^0 decay simulates the direct decay of the K_2^0 into two π mesons. By this ingenious method, the apparatus was calibrated with sufficient exactness to thor-

oughly establish this decay mode for the K_2^0, should it occur. The regeneration material was then removed, and *decays were still observed that were identical with those from the regenerated* K_1^0 *mesons.*

It was very important to eliminate the possibility that these decays were in some way simulated by the normal 3-body decay modes of the K_2^0. A careful analysis of all the events showed that there was very little chance that a 3-body decay could be mistaken for a 2-body decay because of two special conditions, both of which had to be met. In a 3-body decay, the vector sum of the momenta of the decay products must make zero angle with the direction of the K_2^0 beam. This is equivalent to saying that for the decay products the sum of the momenta transverse to the beam must equal zero in order to conserve momentum, since the K_2^0 from which they originated has momentum only in the direction of the beam. In addition, the conservation of energy requires that the sum of the kinetic energy and the rest mass energy of the decay products must equal the sum of the kinetic energy and the rest mass energy of the K_2^0. The data were corrected for the few 3-body decays satisfying these two requirements. The experimenters thus concluded, as the most reasonable explanation of the observed events, that the K_2^0 meson decays into two π mesons at the rate of ≈ 2 in every 1000 decays. This process violates CP invariance and strongly implies that time reversal invariance does not hold, since CP and T are interdependent through the invariance of CPT, which appears to be firmly established for all interactions. Heretofore, it had been believed that the

Figure 3. The spectrometer array for the neutral K-meson experiment. The two magnets are nearly hidden by the housings of the spark chambers and cameras. A mirror system within the housing makes it possible to include the spark chamber preceding and the one following each magnet in one photograph, which simplifies the analysis procedure. A scientist is checking the complex electronic equipment of the triggering system.



direction of time had no influence on the laws of physics. This may no longer be so, and further work is in progress to check this result, which would have far-reaching implications.

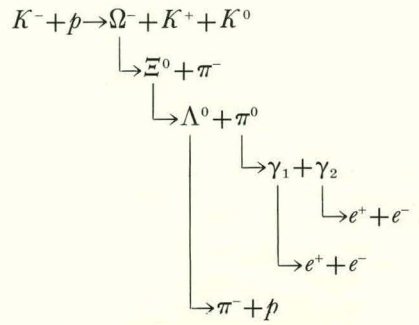
It is now apparent that the strongly interacting isotopic multiplets can be grouped into supermultiplets whose members have the same angular momentum (spin) and parity. The supermultiplets, which also include the resonant states of the baryons and mesons, show a remarkable orderliness when analyzed on the basis of strangeness, isospin, and baryon number. Gell-Mann and Ne'eman have developed a mathematical theory based on a special unitary symmetry group known as $SU(3)$, or the "eighfold way," which may prove to be the mathematical foundation underlying the structure of the system of baryons and mesons. Evidence supporting this theory has accumulated in the past few years. Some resonances – the Y_0^* (1520 MeV) singlet (isospin = 0), the Y_1^* (1660 MeV) triplet (isospin = 1), and others – have no place in the scheme, but up to this time the theory has successfully described a large number of other particle and resonance families:

		Spin	Parity
Pseudoscalar meson octet	π,K,η	0	−
Vector meson octet	$\rho,K^*,(\omega,\varphi)$	1	−
Baryon octet	Σ,N,Ξ,Λ	½	+
Baryon decuplet	$N_{3/2}^*,Y_1^*,\Xi_{1/2}^*,(?)$	3/2	+

However, one member of the baryon decuplet had not been discovered. Figure 4 illustrates the position of the nine known resonant states and the predicted tenth particle plotted as a function of mass and the third component of isospin. As can be seen from the figure, this particle (called Ω^-, following Gell-Mann) is predicted to be a negatively charged isotopic singlet with strangeness −3. The spin and parity should be the same as those of the $N_{3/2}^*$, namely, $3/2^+$, but it would have a long enough lifetime ($\approx 10^{-10}$ sec) to be classified as a particle rather than a resonance. Consequently, the existence of the Ω^- particle has been cited as a crucial test of the theory of unitary symmetry of strong interactions. The mass is predicted by the Gell-Mann–Okubo mass formula to be ≈ 1680 MeV/c^2. Many laboratories have been engaged in an effort to find and identify such a particle.

In February of this year a BNL team announced the observation of the production and decay of the sought-for Ω^-. More than 30 scientists, including 3 from Syracuse University and 1 from the University of Rochester, were directly involved in the experiment. The 80-in. hydrogen bubble chamber was exposed to the new mass-separated beam of 5-BeV/c K^- mesons at the AGS. About 100,000 pictures were taken containing a total K^- track length of $\approx$1 million ft. These pictures were analyzed for the more characteristic decay modes of the Ω^-.

An event is shown in Figure 5 which has been interpreted as shown below.



From the momentum and gap length measurements track 2 is identified as a K^+. A bubble density of 1.9 times the minimum was expected for this track, while the measured value was 1.7 ± 0.2. Tracks 5 and 6 are the signature of a V particle which can be either a Λ or a K^0. These tracks, however, have the proper characteristics to be the

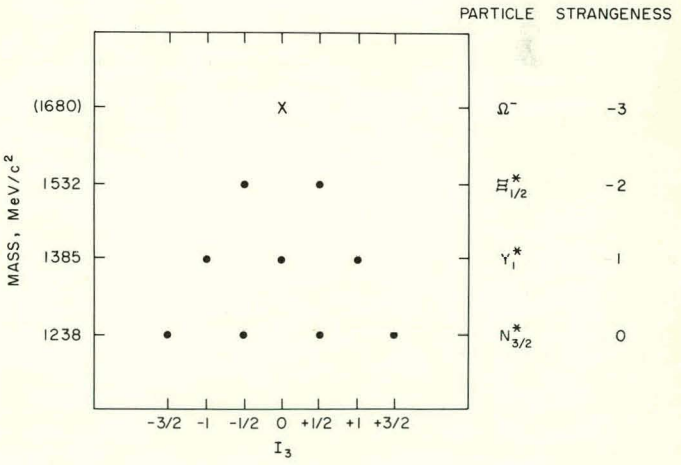


Figure 4. The supermultiplet (decuplet) of particles with total angular momentum (J) = 3/2 and positive parity, plotted as a function of mass vs the third component of isospin (I_3). The particle subscripts give the total isospin (I) assignment of the multiplets and hence indicate the number of possible charge states equivalent to $2I+1$.

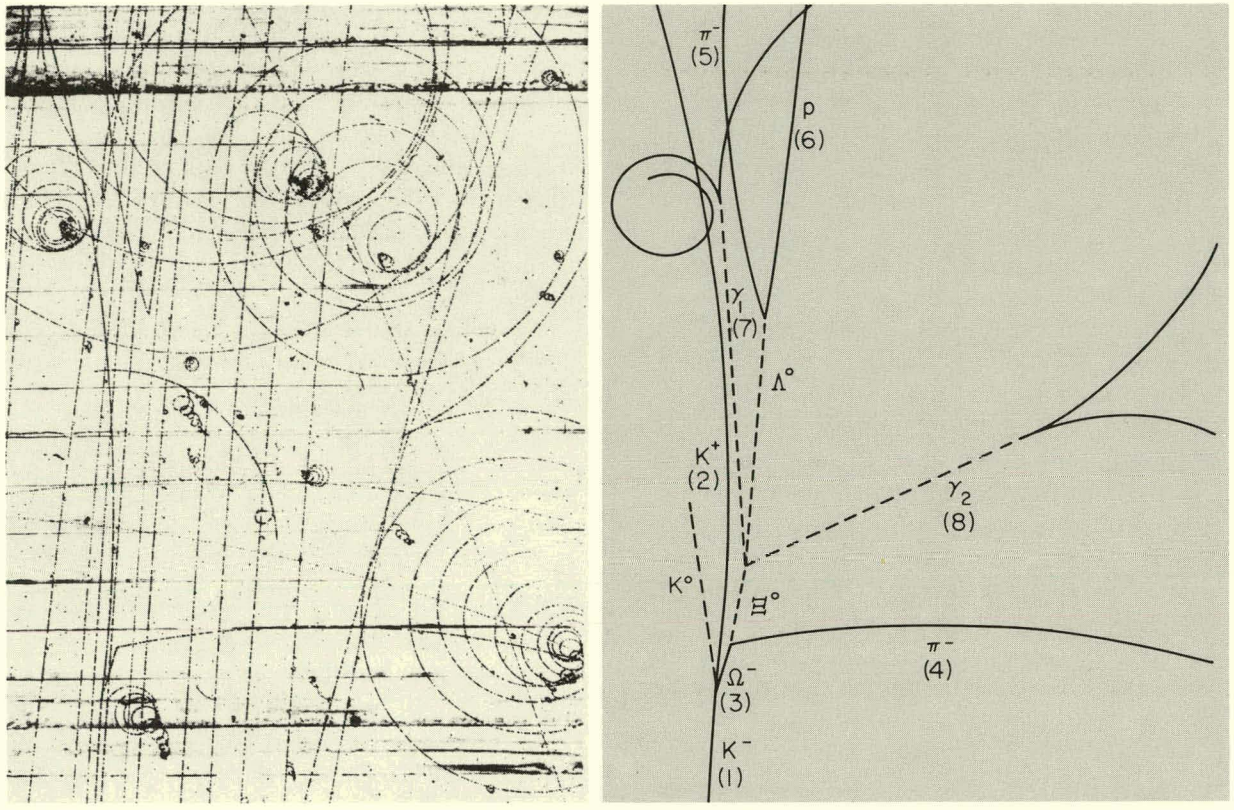


Figure 5. Photograph of the event in the 80-in. hydrogen bubble chamber which resulted in the discovery of the Ω^- particle .The accompanying line drawing shows the track identification established by detailed analysis of the event (see text).

decay products of a Λ, a proton, and a π^-. The curvature of these tracks in the magnetic field of the bubble chamber makes it possible to calculate the momenta of the proton and the π^-. The Λ mass calculated from the measured proton and π^- kinematical quantities (governed by momentum and energy conservation) is (1116 ± 2) MeV/c^2, within <1 MeV/c^2 of the accepted value. It is important to be sure that the V particle is not a K^0 masquerading as a Λ. If this were so, the positive decay product would be a pion instead of a proton. Since the bubble density from gap length measurement of track 6 is 1.52 ± 0.17, compared to 1.0 expected for a π^+ and 1.4 for a proton, the interpretation of the V as a K^0 is unlikely. The kinematics also permit a reconstruction of the Λ line of flight and eliminate the possibility that it might have come from the primary interaction of the incoming K^-. The Λ appears six decay lengths from the wall of the bubble chamber, which makes it extremely unlikely that it originated there. The photograph shows no other visible origin in the chamber. It therefore seems clear that the Λ originates from the decay of some other neutral particle, and indeed the identity of such a neutral particle was established from the following analysis.

It is unusual and fortunate that two γ rays which proved to be associated with the event converted to electron positron pairs in the liquid hydrogen. From measurements of the electron momenta and angles, the effective mass of the two γ rays is found to be (135.1 ± 1.5) MeV/c^2, consistent with a π^0 decay. The π^0 lifetime is so brief that it moves an undetectably short distance before it decays into two γ rays. In a similar manner the calculated π^0 momentum and angles and the values already calculated for the Λ are used to determine the mass of the neutral decaying particle which gave birth to the Λ. The result is (1316 ± 4) MeV/c^2, in excellent agreement with that for the Ξ^0 hyperon. The projections of the lines of flight of the two γ's and the Λ intersect within the error of observation. The computed line of flight of the Ξ^0 leads back to the decay point of track 3, but properly misses the

production vertex of the primary interaction. It is 3 cm in length, which is quite consistent with the Ξ^0 lifetime and the calculated momentum of (1906 $\pm$20) MeV/c. It was also established that the transverse momenta of the Ξ^0 and of the track 4 particle were equal and opposite within errors, which indicated that no other particle was emitted in the decay of particle 3. The next step was to establish that track 4 was a π^- meson. From the momentum and gap length measurements it was concluded that its mass was less than that of a K. The measured transverse momentum of this track, (248 $\pm$5) MeV/c, also added another piece of evidence to establish the identity of particle 3. This value was greater than the maximum momentum for the possible decay modes of all the known particles except for the $\Xi^- \rightarrow e^- + n + \nu$. This possibility was rejected, however, because the previously established association of a Λ and two γ's with the event had clearly indicated that the decay of particle 3 involved a Ξ^0, and a Ξ^- is not massive enough to decay into a Ξ^0 and a π^- meson. Using the Ξ^0 momentum and assuming particle 4 to be a π^- meson, the mass of particle 3 could be computed; the result was (1677$\pm$9) MeV/c^2. Its momentum was measured to be (2015$\pm$20) MeV/c. By using this value and its measured track length, the proper lifetime of particle 3 was calculated to be 0.7×10^{-10} sec. Since it lived this long, it could have decayed only by weak interaction which in turn means a change in strangeness – $\Delta S = 1$. Since the decay product was the Ξ^0 with $S = -2$, this means that particle 3 must have had $S = -1$ or $S = -3$. But $S = -1$ is ruled out because particle 3 would then have decayed by strong interaction (with $\Delta S = 0$) into a smaller hyperon and meson ($Y + \pi$) and would not have lived long enough to leave a track in the chamber. It may thus be concluded that particle 3 has strangeness -3. The balance of the masses and energies at the production vertex show the missing mass of (500$\pm$25) MeV/c^2 which has not been accounted for. This is in good agreement with the mass of the K^0, the final member of the reaction.

In view of the properties of charge equal to -1, strangeness equal to -3, and mass equal to (1677$\pm$9) MeV/c^2 established for particle 3, it is clear that it may be identified as the Ω^-.

Still another Ω^- has been observed; however, it decays by a different mode into a $K^- + \Lambda$.

Continuing their study of elastic scattering, a Brookhaven counter group has extended the incident energy range (to $\approx$25 BeV) and the accuracy of their measurements by using high energy pion and K mesons, protons, and antiprotons incident on hydrogen. The study of nuclear elastic scattering as a function of momentum transfer essentially probes the nuclear interaction potential density distribution as a function of distance from the center of the proton, just as the study of electron-proton scattering probes the electric charge density distribution as a function of distance.

All previously observed characteristics of the interactions observed at lower incident energy ($\approx$7 to 20 BeV) were found to persist at higher incident energies. For example, the size of the p-p interaction radius continues to grow with increasing energy (i.e., the diffraction pattern shrinks). The $\pi^{\pm}$-p radius shows no energy dependence, the $\bar{p}$-p interaction radius decreases with increasing energy, the K^--p radius seems to be independent of energy, but the K^+-p radius, as previously found, increases with increasing energy. The average $\pi^{\pm}$-p, p-p, and K^--p radii are $\approx$1.1 fermis, the K^+-p radius is smaller ($\approx$0.95 fermi), whereas the $\bar{p}$-p radius is largest ($\approx$1.35 fermis). The antiproton is the most opaque object, the proton has a medium opacity, and the pions and kaons all appear to be the least opaque ($\approx$half transparent).

Until recently, it was assumed by most theorists that at high energy ($\gtrsim$10 BeV) the elastic scattering amplitude was almost completely imaginary, corresponding to the shadow scattering generated from inelastic (particle-producing) interactions, and that there was either no or a very small real part of the effective interaction potential corresponding to scattering interactions not connected with particle production.

Although previous experiments of this Brookhaven counter group had implied such real amplitudes in $\pi^{\pm}$-p interactions and these and experiments of other investigators (notably Russian and European) had implied such real amplitudes in p-p interactions, deficiencies in both the experiments and the analyses prevented a definitive conclusion.

Very recently the Brookhaven counter group did a much more accurate, high-resolution, small-angle scattering experiment (Figure 6) which conclusively proved that there are sizable real amplitudes ($\approx$15 to 30% of the imaginary) in the incident energy range 8 to 12 BeV in $\pi^{\pm}$-p scattering. They used the very sensitive method of observing

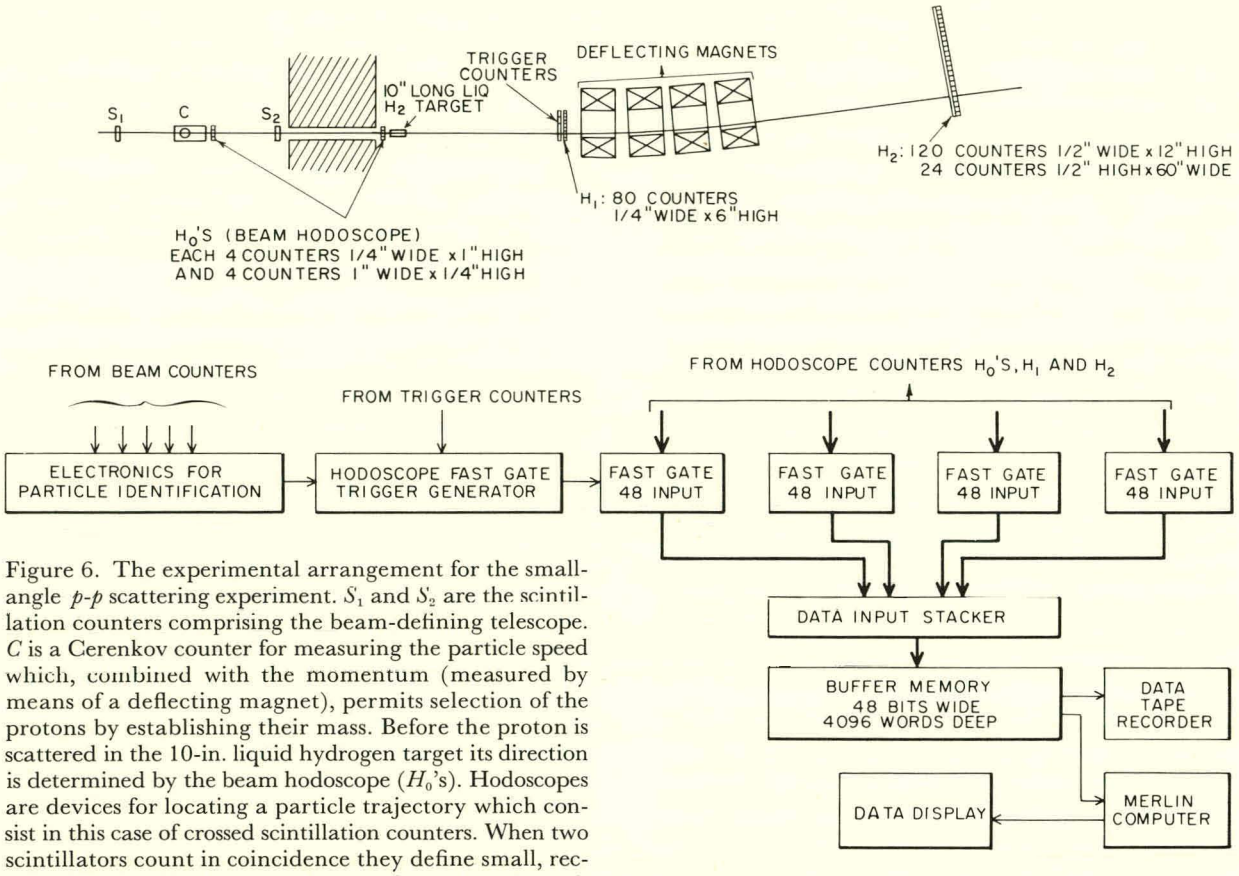


Figure 6. The experimental arrangement for the small-angle p-p scattering experiment. S_1 and S_2 are the scintillation counters comprising the beam-defining telescope. C is a Cerenkov counter for measuring the particle speed which, combined with the momentum (measured by means of a deflecting magnet), permits selection of the protons by establishing their mass. Before the proton is scattered in the 10-in. liquid hydrogen target its direction is determined by the beam hodoscope (H_0's). Hodoscopes are devices for locating a particle trajectory which consist in this case of crossed scintillation counters. When two scintillators count in coincidence they define small, rectangular areas indicating the specific region through which a charged particle has passed. The direction of the proton after scattering is determined by hodoscope H_1. The deflecting magnets and hodoscope H_2 determine the momentum. The counter logic and data-handling arrangement are illustrated in the block diagram.

the direct interference with the Coulomb amplitude (constructive in π^+-p and destructive in π^--p), which is almost predominantly real. The nuclear real amplitude sign was determined to be negative in both cases, corresponding to a repulsive potential interaction. In the p-p scattering, a similar destructive interference effect was also observed by this group and by groups at CERN and Dubna, but since both protons have a spin the effect could also be due to a spin-dependent interaction. In the $\pi^{\pm}$-p case this is not a problem, since the pion is spinless. The $\pi^{\pm}$-p result thus appears to fortify the probability that the p-p result is due to the real amplitudes.

These results (especially those for $\pi^{\pm}$-p) are of considerable significance from a theoretical point of view, but they are of particular significance for checking the prediction of the forward dispersion relations which are generated by the assumption of causality. They can also be used as a sensitive check of various high energy asymptotic theorems.

The role of the muon in the particle scheme is puzzling. In many respects the muon behaves exactly like a heavy unstable electron. It is important to detect any other underlying differences in behavior or character that might account for its large mass relative to the electron. An experiment to this end, briefly mentioned last year, has now been sufficiently analyzed so that preliminary results are available. A team of BNL, Columbia University, and University of Rochester physicists measured the muon-proton elastic scattering at high momentum transfers. The muon beam resulted from the decay of 6 to 10-BeV/c pions held together over a 50-m flight path by a beam transport system of 14 quadrupole magnets. About 10% of the pions decayed in flight and produced muons which were also contained by the transport system. The beam passed through a cylindrical iron collimator 12.5 m long in which the first 9.5 m were filled with concrete to act as a filter against pions. The emergent beam of muons had a momentum spread of 1.5 to 6 BeV/c (peaked at 2.5 BeV/c) and an angular divergence of $<1°$. The

intensity was $\approx 10^{-5}$ times the circulating proton beam intensity in the accelerator. Since the π-p elastic scattering is known to be $\approx 10^4$ times larger than the μ-p cross section at these momenta, only a very small contamination of pions could be tolerated. The concrete-filled collimator was equivalent to 19 mean free paths for absorption of pions of 6-BeV/c momentum and thus attenuated pions by a factor of $\approx 4 \times 10^7$. Additional discrimination against pion scattering effect was provided by requiring that the recoil muon traverse 1.2 m of iron-loaded concrete, which further reduced the pion contamination by a factor of ≈ 10. Taking into account the initial proportion of π mesons to muons, $<0.1\%$ of the events measured should have resulted from π-meson scattering. Tests with the absorbers removed confirmed this expectation. The muons were scattered by protons in a liquid hydrogen target. The scattered muon and the recoil proton were detected by a complex array of spark chambers, counters, and absorbers which permitted measurement of the scattering angles of both particles and the range of the recoil proton. This provided more than enough information to eliminate all events that were not truly elastic scattering.

From a comparison of these results with those from electron-proton scattering, the charge and magnetic form factors (the shape and extent of the charge and magnetic field) of the proton appear to be the same to a muon and an electron. The size of the muon had been determined in other experiments to a much greater accuracy than had been possible for the electron. This experiment shows, however, that they appear to be the same size within the accuracy of the measurement of the muon size. So to this accuracy still another possible electron-muon source of dissimilarity has been eliminated.

Information on the structure of the elementary particles at very small distances is obtained by studying collisions involving high momentum transfers. The simplest of such collisions, as regards both the experimental technique and the theoretical interpretation of experimental measurements, are the large-angle elastic collisions. Continuing their previous work, a Cornell University–Brookhaven team carried out an experiment to measure proton-proton elastic scattering cross sections at energies and momentum transfers up to the highest values obtainable at any proton accelerator. The experimental layout is shown schematically in Figure 7, and a partial view is shown in Figure 8. By changing the positions of the analyzing magnets and collimators, the observed angles of the scattering protons could be varied over a sufficiently wide range. The numerous channels through the shielding were provided for this purpose.

The internal proton beam of the AGS is scattered by hydrogen in a polyethylene (CH_2) target. The scattered and recoil protons leaving the target pass through collimators placed at the calculated angles corresponding to a particular beam energy. Then the protons pass through deflection magnets tuned to select the calculated momenta. Following these magnets are the left and right counter telescopes which identify an elastic p-p scattering by a left-right coincidence. The only significant background encountered with this technique was found to be due to accidental coincidences between unrelated particles in the two telescopes. Coincidences were displayed by using a time-to-pulse-height converter feeding into a pulse-height analyzer. By this means it was possible to record the time separation of the two pulses making each coincidence. Full width at half-maximum of the peak observed in the pulse-height analyzer was 2×10^{-9} sec. The accidental coincidence rate could be measured from the background level outside the region of the true coincidence peak.

To reduce the counting rate and thus minimize accidental coincidences, fairly thin targets were used. Problems of melting and hydrogen depletion were overcome by using a 1-mm-thick CH_2 wheel which rotated several degrees with each flip of the target.

The contribution to the coincidences due to the presence of carbon in the CH_2 target was measured by using a pure carbon target and was found to be $<2\%$ of the effect observed with the CH_2 target. This is consistent with an estimate of the quasi-elastic scattering of protons on protons in the carbon nucleus. Hence the coincidences observed with polyethylene targets were practically all due to elastic scattering by hydrogen.

Any coincidences due to inelastic interactions with the hydrogen should occur with the carbon as well. Since pion distributions from carbon and hydrogen are similar, it was expected that the inelastic background would also be $<\approx 2\%$. This has been confirmed by several other tests. When-

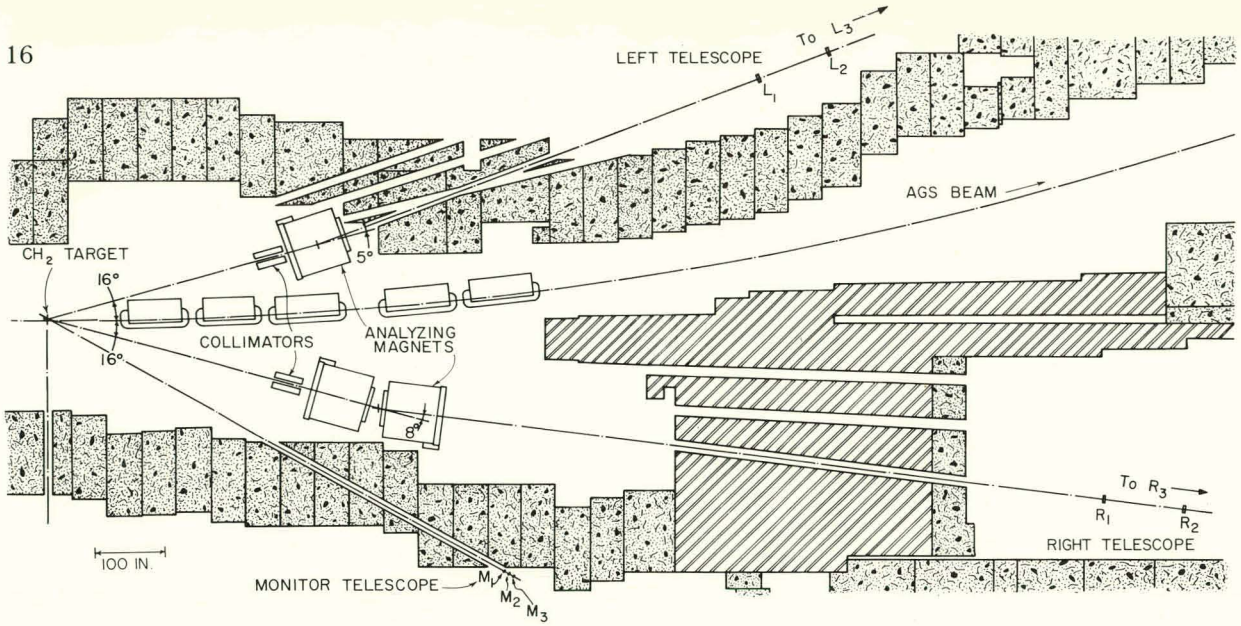


Figure 7. Layout for the high momentum transfer p-p scattering experiment. The AGS primary beam of protons was elastically scattered by protons in the polyethylene (CH_2) target (left). The recoil and scattered protons passed through collimators which selected the scattering angle to be observed corresponding to a preset primary proton energy. The protons then proceeded through the momentum analyzing magnets, also at preset values, and were detected by scintillation counters which constitute the left and right telescopes. A coincidence count from these two telescopes signaled an elastic scattering event. The supplementary beam channels were later used for other scattering angles and other values of momentum transfer. For simplicity, only 5 of the ring of 240 AGS beam magnets are shown.

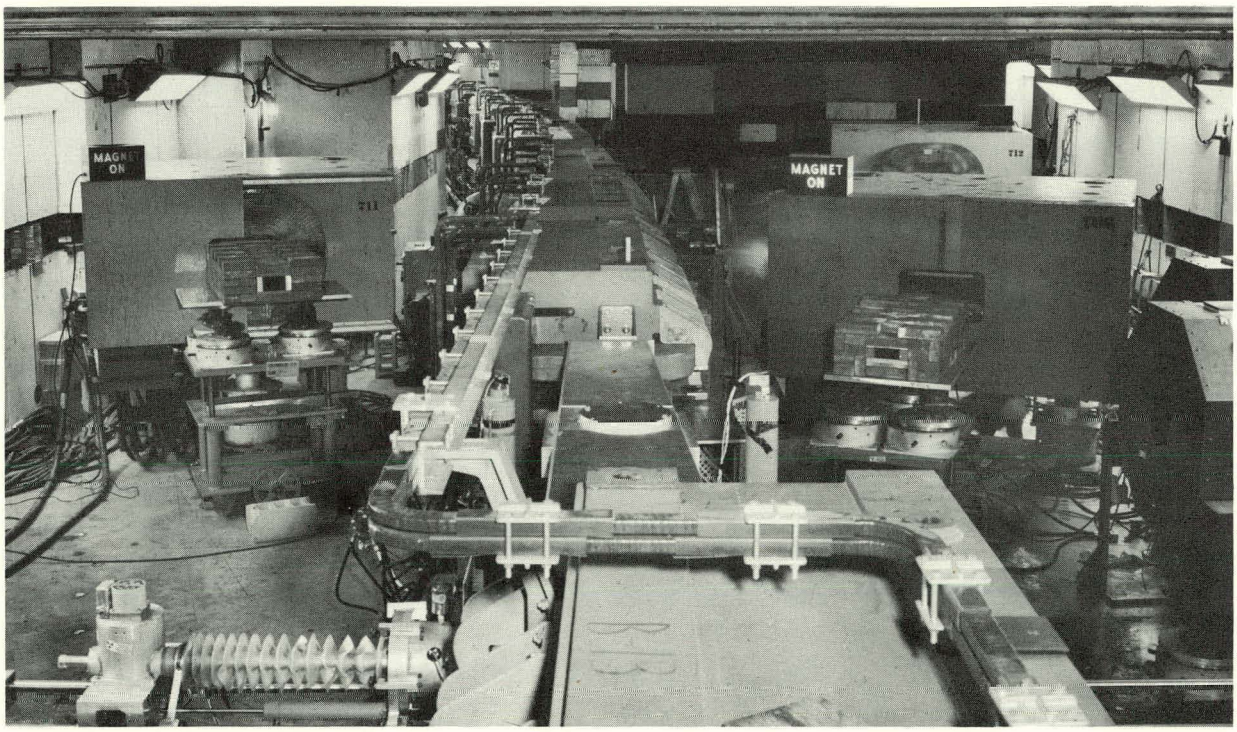


Figure 8. Part of the high momentum transfer experimental setup. The magnets that guide the AGS primary beam are shown in the center. The CH_2 target is located directly under the circular porthole in the 10-ft-long thin-window target box (center foreground). The collimators and deflecting magnets which define the scattering angles and momenta of the recoil and scattered protons flank the magnet ring.

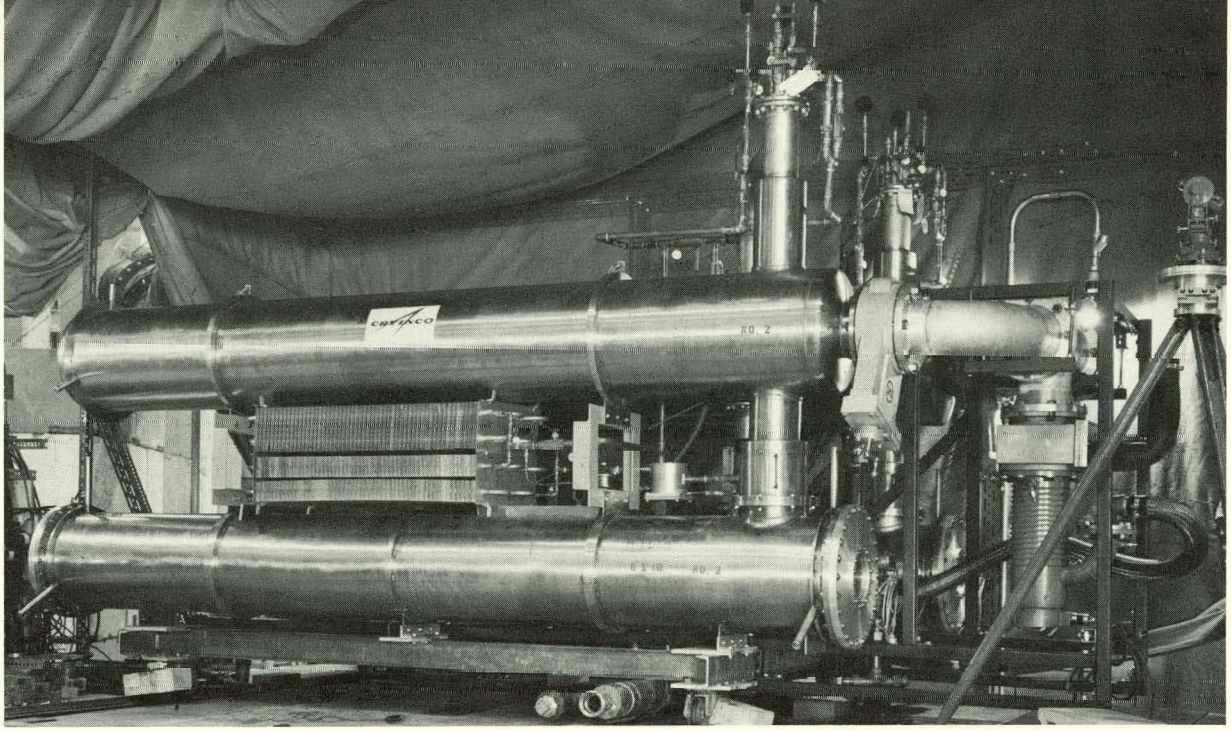


Figure 9. The 10-ft liquid hydrogen targets being positioned on the beam line for the high-precision total cross section experiment. The upper cylinder is the reservoir. The lower cylinder contains a double-jacketed cylinder, both compartments of which are filled with liquid hydrogen. The hydrogen in the outer compartment is kept at constant pressure to maintain the inner compartment at constant temperature. The π-meson beam enters from the left and emerges through the thin-window port at the right end of the lower cylinder, behind which an identical dummy setup with an evacuated inner cylinder can be seen. All sections containing liquid hydrogen are surrounded by a superinsulated evacuated region.

ever the beam energy or magnet currents were changed by several percent from their calculated values, the coincidences disappeared. When the counter sizes on both telescopes were reduced, the coincidence rate decreased proportionally.

The most striking feature of the results of the *p-p* elastic scattering experiment is that the shapes of the observed angular distributions at different incident energies are similar over the complete range of scattering angles (0° to 90° c.m.) and in fact appear to be almost constant over $\approx$40% of the range (65° to 90° c.m.). The highest momentum transfer value at which a measurement was made corresponds to an interaction distance of 0.04 fermi (4.0×10^{-15} cm). An empirical equation, with the cross section decreasing exponentially with transverse momentum, provides a good fit to the data over a region in which the cross section decreases by a factor of 10^7. It is remarkable that this same expression also describes a transverse momentum distribution of pions produced in nucleon-nucleon collisions. At present the relationship between this empirical formula and the structure of the nucleon or the properties of strong interactions is not clear, but it might be an indication that the nucleon lacks any outstanding structure for elastic scattering interactions at high energy and high momentum transfer. In contrast to the search for the Ω^-, this experiment was not undertaken to test any known theory but rather to provide fundamental knowledge in a hitherto unexplored region, which theory must explain.

The graphs of the energy dependence of a number of strong particle interactions exhibit peaks. In some cases the peak is interpreted to be a resonance, in other cases, a particle. It is evident that there is no clearly defined recipe for designating a particle. The especially short-lived states of the strongly interacting particles are generally termed resonances. These states decay into the constituent particles in times of the order of 10^{-23} sec, about the time it takes a π meson at the speed of light to travel a distance equal to the diameter of the proton. In contrast, the much more stable particle, the newly discovered Ω , has a very much longer lifetime ($\approx10^{-10}$ sec). These resonant states, like their longer-lived counterparts, have characteristic quantum numbers for angular momentum, isospin, parity, etc. The search for these resonances is continuing to produce interesting results.

A counter group at Brookhaven which included visiting physicists from Harwell, England; Saclay, France; and CERN have discovered two new pion-nucleon resonances in the measurement of total cross sections of $\pi^{\pm}$ mesons on protons. This high precision measurement in the momentum interval from 2.5 to 5.5 BeV/c was obtained with a statistical accuracy of 0.05% for π^{-}-p and 0.08% for π^{+}-p cross sections at momentum intervals of 100 MeV/c. Previous measurements in this momentum region with much poorer statistics had not revealed any structure.

The object of this experiment was to measure the relative total cross sections as a function of momentum to a precision never before attempted. The pion beam was designed to provide enough pions/pulse of the AGS so that, even at the highest momentum setting, millions of counts could be accumulated in a reasonable running time. As a result, the statistical accuracy was never a problem. However, it was consequently extremely important to control systematic factors that might vary with time. All the counter signals were split and sent to two parallel sets of electronic equipment of different types to provide a check on any drift in the electronic circuits. Two linear-output scintillation counters, placed before and after the counter defining the final beam, provided a means of pulse-height discrimination which reduced the 2-fold accidental counting rate by a factor of 100. This essentially eliminated any dependence of the results on fluctuations in beam intensity. The ambient temperature for the electronic equipment was maintained to $\pm 2°$F. The magnet defining the momentum was controlled to $\pm 0.05\%$ by using a nuclear flux meter. The 10-ft hydrogen target (Figure 9) was of special double-jacketed design to provide long-term stability of the hydrogen density. The outer cylinder was filled with liquid hydrogen at a controlled vapor pressure, maintained constant to $> \pm 0.4\%$, to provide a constant-temperature bath for the inner cylinder. The liquid hydrogen in the inner cylinder was sealed off to ensure a bubble-free liquid with density constant to $> \pm 0.03\%$. The reservoir for the outer cylinder required filling only once every four days, which allowed long undisturbed periods for taking data. An identical system, with the inner cylinder under vacuum, was used as a dummy to permit elimination of effects produced by the windows and insulation of the hydrogen target.

The counter outputs, which registered on scalers, were transferred by a scanning system onto punched tape. A typed record of the scaler counts was also provided. The data on the tape were transferred to IBM cards which were then processed through an IBM 7094 computer to check the data for internal consistency and to calculate the cross sections. The cross sections measured simultaneously with the two sets of electronic equipment agreed to within $\pm 0.2\%$ over the complete range. In measuring the π^{-}-p total cross sections, an iron filter, placed behind the transmission counters and followed by an additional counter, was used to eliminate the effects of muon contamination of the beam. However, the signal from this final counter was not included in one set of electronic equipment. Despite this, the same resonance was observed in the data from both sets, although the absolute values of the cross sections were different, as would be expected because of the muon background. The method of taking data clearly indicated that a possible variation in the muon contamination was not causing a spurious resonance.

The resonances were found to have masses of 2.645 MeV with a width of 23 MeV and 2.825 MeV with a width of 26 MeV and were interpreted to be isospin ½ and 3/2 states, respectively, in the pion-nucleon system. Thus, resonances continue to recur with alternating isospin states, as has been empirically suggested from data at lower momenta.

Very recent π^{-}-p charge exchange data observed in the forward direction also give indication of structure. This work was carried out at the AGS by a group from MIT. There is qualitative agreement between their data and the results of the BNL group described above. There is, however, some quantitative disagreement on the momenta at which the resonances occur. To relate the results of these two experiments, assumptions must be made regarding the real part of the $\pi^{\pm}$-p forward scattering amplitudes, and it may be that the difference can be resolved by further information on this point.

A new meson of strangeness zero has been added to the growing list of resonances. It has not yet received a formal name but has been temporarily designated the X^{0}. It is a 5-pion resonance. An experimental team from Syracuse University and Brookhaven used the BNL 20-in. bubble

chamber to photograph interactions of 2.3-BeV/c K^- mesons with protons. An analysis was made of the following reaction channels:

$$K^-+p\rightarrow\Lambda+\text{neutrals} \quad (1)$$
$$\rightarrow\Lambda+\pi^++\pi^-+\pi^++\pi^-+\pi^0 \quad (2)$$
$$\rightarrow\Lambda+\pi^++\pi^-+(\text{neutrals with } m>m_{\pi^0}) \quad (3)$$

Evidence for the new meson comes from a study of the effective mass and missing mass spectra of these reactions. Such spectra are derived from the energy and momentum balance of the reactions. Peaks in the multimeson spectra indicate the existence of bound states. All 3 channels independently show a peak that rises at least 3 standard deviations above background, which indicates the existence of a neutral particle of $m\simeq 960$ MeV. Careful analysis shows that the full width of the peak is <20 MeV. The data also exhibit the expected peaks for the Λ, π^0, η^0, ω^0, and φ^0, in excellent agreement with their known masses. A study was made of the center-of-mass production angle of the Λ hyperon in channel 3. Λ's emitted strongly in the backward direction are much more common in events in the region of the peak than in events outside this region. This indicates that a different production mechanism is involved in the peak region, with a higher proportion of peripheral events, and lends further weight to the evidence for the existence of the X^0. This new resonance is either a neutral singlet or a member of a charged triplet, since its isospin is either 0 or 1, which is evident from its production by interaction of a K meson ($I=\frac{1}{2}$) with a proton ($I=\frac{1}{2}$). Using the shorthand notation (I,J^P) to indicate isospin, spin, and parity quantum numbers, this experiment strongly indicates that $(0,0^-)$ or $(1,1^+)$ can be the only choice. It is interesting to speculate on the role of the X^0 within the framework of $SU(3)$. If the assignment $(1,1^+)$ should be verified, the X^0 presumably heralds the existence of a new unitary multiplet. On the other hand, if $(0,0^-)$ is proved correct, the X^0 might be accommodated as a unitary singlet accompanying the pseudoscalar octet comprised of the π mesons, K mesons, and the η meson. Since the quantum numbers of the η and X^0 are the same, mixing between these two states can in principle occur. However, since the η mass shows quite good agreement with the Gell-Mann–Okubo mass formula, this mixing must be small, which is reasonable considering the high mass value of the X^0. This is in contrast to the vector meson case in which the ω and φ must mix quite strongly in order to fit the predictions of the formula (see last year's report). It is also of interest to note that recent generalizations of $SU(3)$ have predicted the existence of a ninth 0^- meson. The production cross section was roughly measured as 60 microbarns, comparable to that for the η and φ mesons. The predominant decay mode is

$$X^0\rightarrow\pi+\pi+\eta\,.$$

The first observation of a resonance between a pion and a multipion resonance was made by a group from the University of California at La Jolla. An analysis of photographs of π-p interactions from exposures of the BNL 20-in. bubble chamber revealed the existence of a π-ω resonance which has been named the B meson. It has a mass of $\simeq 1.22$ BeV and a width of 100 ± 20 MeV. The data favor spin of $L=1$ and negative parity, but the statistical limitations and background do not permit elimination of other assignments. It was pointed out by this group that the mass and width correspond to those of the f^0 meson whose discovery was noted in last year's report. They further suggested that the f^0, which at that time was known to decay only into $\pi^++\pi^-$, might simply be the neutral decay mode of the B. A Michigan group, using π^--p interactions photographed in the 20-in. bubble chamber in an attempt to determine the spin of the f^0, tentatively concluded that the f^0 and B probably were not the same particle, since their data favored $L=2$ as opposed to $L=1$ for the f^0.

The California workers had also indicated that a more definitive test would be the decay of the $f^0\rightarrow\pi^0+\pi^0$. If this occurred, the f^0 must have even spin, and the hypothesis that the B and f^0 were the same would be ruled out. An MIT group working at BNL demonstrated how spark chamber and counter experiments can complement the use of bubble chambers. Utilizing apparatus designed and constructed for their charge exchange experiment (mentioned earlier), the Cambridge group definitely established that the f^0 decayed into two neutral π mesons and thus the B and f^0 mesons could not be identical. They also concluded that the f^0 had positive parity and verified the fact that its isospin was even.

At about the same time a group from Columbia, in a study of π^+-d interactions in photographs from the 20-in. BNL bubble chamber, confirmed the

counter results and showed that the isospin was 0 by establishing that the f^0 decayed half as often into neutral as into charged π mesons. Further work by the Michigan group, also using π^+-d pictures from the 20-in. bubble chamber, independently and almost immediately verified these results by a similar type of analysis.

A group from the University of California at Berkeley using the Brookhaven 20-in. hydrogen bubble chamber have found evidence for another resonance between a pion and a multipion resonance, in this case the ρ. They observed the π-p resonance in π^+-p reactions and tentatively assigned to it a mass of 1.2 BeV with a width of 350 MeV and isospin $I=1$ or 2.

Pictures containing 150,000 stopped $\bar{p}$ have been shared equally between the University of Rome, Syracuse University, and BNL. Scanning is complete on all pictures, and nearly all strange particle events have been measured. The so-called FOG-CLOUDY-FAIR system of programs is now working and is being used in this experiment, and analysis of the events is in progress. Several thousand 4-prong events of the type $\bar{p}+d\rightarrow p+3$ charged tracks (where the p is visible) have been measured, and preliminary analysis of some 900 such events gives an upper limit for ω^0 production:

$$\bar{p}+n\rightarrow\omega^0+\pi^-\lesssim(7\pm3)\times10^{-3}$$
of all $\bar{p}$-n annihilations at rest.

In comparison, BNL workers find a preliminary rate for production of

$$\varphi^0+\pi\ =(7\pm3)\times10^{-4},$$

where the φ^0 is seen in both K^+-K^- and K^0-$\bar{K}^0$ decay modes.

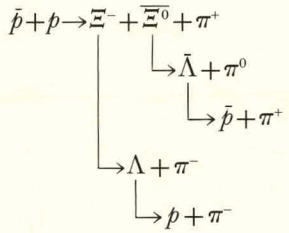
Charged pion multiplicities, given below, total $\approx$97% of all $\bar{p}$-n annihilations:

1π	3π	5π	7π
(15.8±0.4)%	(57.0±0.7)%	(23.6±0.5)%	(0.44±0.06)%

In addition, kaons are produced in $\approx$3% of events as estimated by scanning for K^0 decay products and $K^\pm$ mesons by ionization density vs curvature. The ratio of annihilations on neutrons to annihilations on protons is $\bar{p}n/\bar{p}p=0.75\pm0.02$.

Interesting new results have come from the work on hyperons and hyperon resonances.

During the year the antiparticle of the neutral cascade hyperon was finally observed as one of the products of the annihilation of an antiproton by a proton. This was the last unobserved antiparticle of the then known stable and quasi-stable particles. Proof of its existence was confidently expected, since all other antiparticles had been established and the basic particle-antiparticle symmetry in nature well supported. Only failure to find the $\overline{\Xi^0}$ would have had real significance. The search for the particle was difficult, however, because it is the neutral member of the cascade doublet and itself decays into two other neutral particles, the Λ and the π^0. Since neutral particles do not leave tracks in a bubble chamber, the production and decay reaction had to be reconstructed from the final charged particle products of the Λ and $\bar{\Lambda}$ decays. The event was observed by a Yale-BNL team using photographs taken in the 20-in. bubble chamber. It was possible to establish the existence of the $\overline{\Xi^0}$ without any ambiguity, and many cross checks were provided to make the identification certain in spite of the fact that neither it nor its immediate decay products were observable. The observed reaction was



An experiment is under way to measure the spin and parity of the hyperon resonance with mass 1660 MeV, the Y_1^* (1660). An exposure of the 30-in. hydrogen bubble chamber yielded 180,000 pictures at 9 K^- momenta between 600 and 840 MeV/c. The first results from the analysis show the effect of the Y_1^* (1660) in the reaction $K^-+p\rightarrow\Lambda+\pi^0$ for K^- momenta such that the total energy in the center of mass is near 1660. The variation of Λ polarization with energy indicates that the spin-parity of the resonant state is probably $\frac{3}{2}^+$ or $\frac{5}{2}^-$. It should be possible to resolve this ambiguity after more events have been analyzed.

Continuing their 20-in. bubble-chamber study of K^--p interactions in the region of 2.3 BeV/c, a Brookhaven group has improved their measurement of the mass and lifetime of the Ξ^- hyperon. The latest results based on 364 decays are $m_{\Xi^-}=1320.4\pm0.3$ MeV and $\tau_{\Xi^-}=(1.8^{+0.16}_{-0.15})\times10^{-10}$ sec. From a sample of 29 Ξ^0 decays they have obtained $m_{\Xi^0}=1313.5\pm2.2$ MeV, yielding $m_{\Xi^-}-m_{\Xi^0}=6.9\pm$

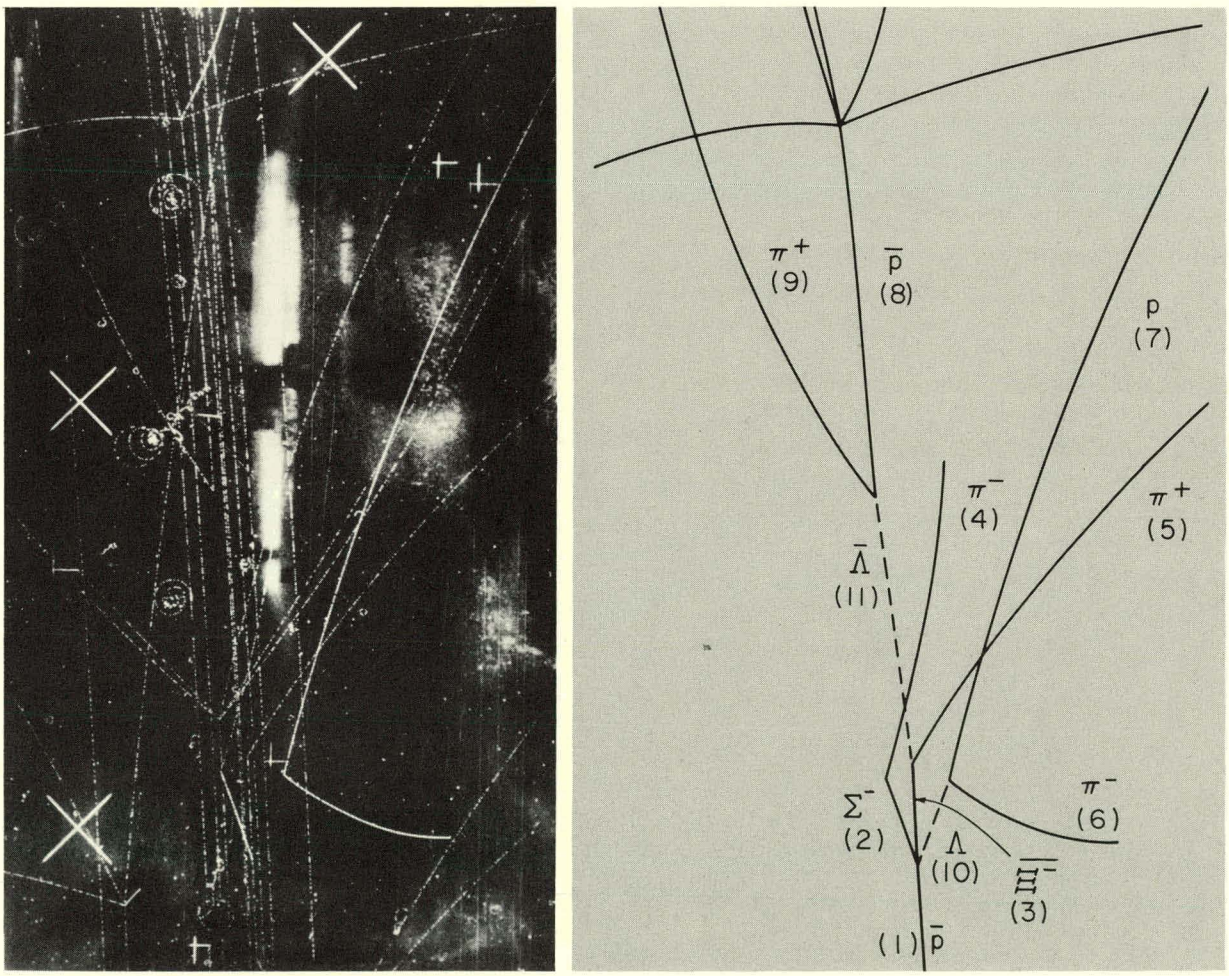
2.2 MeV. This latter result compares very favorably with the $SU(3)$ prediction of 6.7 ± 0.4 MeV.

These K^--p photographs have also been analyzed for the reaction $K^- + p \rightarrow \Xi + \pi + K$. From a study of the Dalitz plot distribution of 368 events, strong production of Ξ^* (1530) and K^* (880) as well as some indication of the κ (730) was observed. This same plot shows no enhancement at a Ξ-π mass of 1600 MeV, which suggests that a proposed $J^P = 3/2^-$ octet consisting of the N^*(1512), Y_0^*(1520), and Y_1^* (1660) is not valid. A study of the decay angular correlations of $\Xi^* \rightarrow \Xi + \pi$ yields isospin $I = 1/2$ and spin $J \geqslant 3/2$ for the Ξ^*.

In research on hyperon production in $\bar{p}$-p interactions at 3.25 and 3.69 BeV/c, measurement of events has been completed and work begun on final statistical summaries. Most of the work was described in last year's report. Preliminary new results on associated production events (Λ^0-K^+-$\bar{p}$, Σ^0-K^+-$\bar{p}$, $\overline{\Lambda^0}$-K^--p, and $\overline{\Sigma^0}$-K^--p) indicate cross sections comparable with those in the corresponding p-p interactions. The processes are characterized by low momentum transfer and show some evidence for the $\overline{Y_0^*}$ (1520) resonance in the K^+-$\bar{p}$ pairs. There is no evidence for other resonant states, but the statistics are small.

A rather remarkable photograph was taken by a group from Brookhaven and Carnegie Institute of Technology in the investigation of the interactions of a separated beam of 2.8-BeV/c antiprotons with deuterium contained in the BNL 20-in. bubble chamber.

Figure 10. An unusual photograph of an observation of the $\overline{\Xi^-}$, the rarely seen antiparticle of the Ξ^-. All the subsequent strangeness-changing decays appeared in the photograph. The tracks are identified in the sketch.



An event of the type

$$\bar{p}+d\rightarrow\Sigma^{-}+\overline{\Xi^{-}}+\Lambda$$

has been observed. Previous observations of the $\overline{\Xi^{-}}$, the rarely seen antiparticle of Ξ^{-}, have been reported in the literature. In the present example production took place on the deuteron, and all the subsequent strangeness-changing decays appeared in the chamber. In addition, the $\bar{p}$ from the decay chain of the $\overline{\Xi^{-}}$ annihilated with a neutron to produce a star of five identified pions. A photograph and a sketch of the event are shown in Figure 10 together with the proposed assignments of the particles.

Formation of $\overline{\Xi^{-}}$ from $\bar{p}$ requires a change of +2 units in both strangeness and charge. This requirement is satisfied for the observed event by a simple 2-step process in which a hyperon-antihyperon pair is produced by K (or by K^{*}) exchange in a $\bar{p}$-nucleon interaction of the antihyperon with the remaining nucleon of the deuteron. It is also satisfied by mechanisms involving virtual $\bar{p}$-nucleon annihilation instead of meson exchange.

The coherent regeneration of the K_1^0 from the K_2^0 mentioned above beautifully illustrates the wavelike quality of particles. This unusual property may be used as a means of establishing the magnitude of the very small mass difference between the K_1^0 and K_2^0. Theory shows that as a result of nuclear interaction with the incoming K_2^0 wave there is a change in the relative phase of the K^0 and $\overline{K^0}$ components which combine to form the K_1^0 and K_2^0 particles observed in the forward direction. The result of this phase change is that the K_2^0 and K_1^0 intensities oscillate back and forth with a frequency depending on their mass difference. Still another effect influencing the K_2^0 and K_1^0 relative intensity is the fact that because of their difference in strangeness the $\overline{K^0}$ component can be absorbed by inelastic processes, while the K^0 component cannot. Both effects enter the mathematical expression relating the mass value to the observed intensities. A Brookhaven group using spark chambers in a neutral beam at the AGS observed the rate of conversion of K_2^0's into K_1^0's for different thicknesses of ion converter. They found the mass difference to be 0.8 ± 0.12 in units of $\hbar/\tau$, where τ is the mean life of the K_1^0 meson. Previous measurements have yielded results that vary between 0.5 and 1.9 $\hbar/\tau$, so there is rather widespread disagreement regarding this quantity.

In an experiment carried out by a combined Rutgers, Columbia University, and BNL team, the decays of the K^0 mesons were studied to test the validity of the $\Delta S=\Delta Q$ rule. This rule, which states that the baryon or meson change in strangeness in a reaction must equal the baryon or meson change in charge, is common to most theories of the strangeness-violating leptonic decays. It predicts, for example, that the decay modes $K^0\rightarrow\pi^{-}+\mu^{+}(\text{or } e^{+})+\nu$ are allowed, whereas $K^0\rightarrow\pi^{+}+\mu^{-}(\text{or } e^{-})+\bar{\nu}$ are forbidden, and vice versa for the $\overline{K^0}$. One of the consequences is that the decay modes in the time distribution of the leptonic decays of a beam that is an incoherent mixture of K^0 and $\overline{K^0}$ would appear to be quite different, depending upon whether or not $\Delta S=\Delta Q$. In this experiment the K^0's were produced in the annihilation of $\bar{p}$'s which stopped in the BNL-Columbia 30-in. hydrogen bubble chamber. With limited statistics, the results were in agreement with $\Delta S=\Delta Q$. Of the 5000 events measured, only 45 met the stringent criteria required to establish the 3-body leptonic decay.

Analysis by Columbia and Rutgers experimenters of the charged K production in these same photographs resulted in a rather precise determination of the masses and lifetimes of the 3-pion resonance known as the ω meson and a K-$\bar{K}$ resonance known as the φ meson, the latter a previously reported Brookhaven discovery. A number of experiments had given limits to the width of the ω, but the width itself had been masked by the experimental resolution. This experiment, however, had sufficiently good resolution to exhibit the natural width. The technique employs the capture of antiprotons at rest in the reactions

$$\bar{p}+p\rightarrow K^{+}+K^{-}+\pi^{+}+\pi^{-}+\pi^{0}$$
$$\rightarrow K^{+}+K^{-}+\pi^{+}+\pi^{-}$$

The results obtained were a mass value for the ω of 784.0 ± 0.9 MeV and a width of 9.5 ± 2.1 MeV, corresponding to a lifetime of $(0.69\pm0.15)\times10^{-22}$ sec. They also obtained partial decay rates for the ω into three π's and into neutrals. Using a similar technique they found the mass of the φ meson to be 1018.6 ± 0.5 MeV with a width of 3.1 ± 1.0 MeV, corresponding to a lifetime ≈3 times that of the ω. It is possible that the measurements of the width of the ω and φ will help to clarify their roles in the conjectured ω-φ mixing in the $SU(3)$ symmetry scheme.

Certain theoretical considerations of the unitary symmetry scheme have suggested the possible existence of fractionally charged particles with charge magnitudes of ⅓ and ⅔ in units of the electron charge. Such a possibility immediately stimulated experimental activity at Brookhaven. Both the 80-in. bubble chamber and counters were used in this investigation. Gell-Mann, who emphasized the importance of investigating the existence of such particles, named them "quarks." They would be found, if they existed, in the form of an isospin doublet with charges of $-\frac{1}{3}e$ and $+\frac{2}{3}e$ and a singlet with a charge of $-\frac{1}{3}e$ with their corresponding antiparticles. The theory shows that at least one of the charge $\frac{1}{3}e$ quarks must either be stable or decay very slowly by β decay into the charge $-\frac{2}{3}e$ quark. No quarks were found in either of the experiments or in similar work done at CERN. It is interesting, however, to see how a counter experiment and a bubble-chamber experiment again complement each other in particle physics research.

The bubble-chamber experiment was carried out by a Pennsylvania group using the 80-in. chamber and an unseparated beam of positive secondaries. The highest possible beam momentum, 8.5 BeV/c, was used in order to cover the largest possible mass range in the hunt for quarks. The fractionally charged particles would be detected through the expected lower bubble density relative to ordinary "minimum ionizing" tracks. It was important to guard against "early" tracks, made before the bubble chamber is fully sensitive, since such tracks also have lower bubble density. Most of these were eliminated by proper timing. As a final check, low-density tracks were carefully examined for δ rays (low-energy recoil electron tracks which always have ordinary density). A δ ray having bubble density similar to that of the track from which it came would identify the parent track as an "early" track and not a fractionally charged track.

The film was scanned twice by physicists and scanners. Sixteen low-density tracks were found but were identified as early tracks. Fourteen had δ rays of low bubble density. The other two had no measurable δ rays, but could also be identified unambiguously as early tracks by virtue of having larger (and therefore older) bubbles than all other tracks in the same pictures.

The counter experiment was carried out by a combined Brookhaven-Yale University team who used a target in the internal 28-BeV proton beam for the production process. The search for quarks was divided into two parts following different assumptions as to the interaction of the quarks. The first method assumed a weak coupling of quarks to regular particles, so that their behavior would be expected to be much like that of muons. It was also assumed that for production of quarks the only coupling of importance was the electromagnetic coupling which was known to be $\frac{1}{3}e$ and $\frac{2}{3}e$. Calculations showed that the production by electromagnetic processes of quark pairs in which the mass of the quark was about the mass of the proton would result in a quark–π-meson ratio of $\approx 500/10^{10}$.

The beam of concern was a mixture of π mesons and postulated quarks produced at the target. The effect of the AGS magnetic field would be the same for pions of momentum p and quarks of momentum $p/3$. In traversing the 40 m between the point of production and the detector counters, ≈ 1.6 kg/cm^2 of varying types of absorber had to be penetrated. After a flight of perhaps 4 m, on the average, the π mesons entered the absorber and were largely eliminated from the beam. Some decayed into muons, which have almost exactly the same direction. The muons and quarks of the appropriate momentum would have nearly the same evolution on their path to the detector, since they are similarly affected by both multiple scattering and magnetic fields. Therefore, the number of muons measured at the detectors would provide a measure of the number of quarks to be expected. The counters were plastic scintillators of a thickness such that the energy loss by a particle with unit charge in one of the counters was ≈ 11 MeV, whereas a quark would lose ≈ 1.2 Mev. The counting system showed no evidence of a charge $-\frac{1}{3}e$ particle. Not one appropriate event was found in a set of events corresponding to the passage of 3×10^7 μ mesons through the detector. Each muon detected was estimated to represent ≈ 300 pions, so that the final sensitivity of the experiment was ≈ 1 quark/10^{10} pions. This was $\approx 0.2\%$ of that expected for the electromagnetic coupling alone. This small number indicated that quarks having an interaction cross section with nucleons of <3 mb and a mass of <2 BeV/c^2 do not exist.

The possibility could not be excluded that quarks interact strongly with nucleons but are still produced with small probability, although

presumably with a probability much greater than that deduced from the electromagnetic coupling alone. The second phase of the experiment covered this possibility. The same apparatus was set up in a beam without the intervening absorber between the primary target and the detector. In this case the limit of the ratio of quarks to pions was established as $<5/10^{10}$, $\simeq 1\%$ of the estimate for electromagnetic production. It was therefore concluded that quarks with a mass of <2 BeV/c^2 do not exist.

Theory

The theoretical group is mainly concerned with the specific and general aspects of the problems of particle physics. Some of the work completed during the past year is summarized below.

A study of scattering amplitudes for high energy was made using perturbation theory. A common method for discussing high energy behavior is to sum the most dominant terms in each order of perturbation theory. In the scalar meson theory with a trilinear coupling this leads to high energy behavior characteristic of an amplitude dominated by a simple Regge pole. For this study, additional terms of the perturbation theory were summed. In particular, the sum of the next most dominant terms in each order was found to be larger than the sum of the most dominant terms, and the dependence on energy was not that of a simple Regge pole. When the class of terms to be summed is further enlarged in a well-defined way, the simple Regge behavior is restored. The question of the high energy behavior of the complete sum remains open.

Crossing relations for scattering amplitudes for particles with arbitrary spin were investigated. Using Lorentz invariance and the assumption that the amplitudes for crossed processes are simply related by analytic continuation, a simple geometrical relation was obtained between these amplitudes. The crossing relations obtained above plus the optical theorem were shown to require that, for forward elastic scattering, the crossed amplitudes with positive parity, positive G-parity, and positive signature cannot be negligible. Hence, if the scattering is dominated by the exchange of a system with definite quantum numbers, the quantum numbers must be those of the vacuum. This result has implications relating to the spin dependence of high energy scattering amplitudes.

By using the impact parameter representation as a method of describing high energy elastic scattering phenomena, the first corrections to the unitarity condition satisfied exactly at infinite energy have been obtained. This method of describing the scattering amplitude was used to examine models of the Van Hove type, and the elastic scattering was obtained as the shadow scattering from multiparticle inelastic processes. Comparison with the high energy π-p elastic scattering data indicates that if the parameters of the model are fixed by the total cross section and elastic-to-total ratio a good fit is obtained on the assumption that the scattering is purely imaginary. In the proton-proton case, however, the simple Van Hove model cannot fit; it seems plausible that the discrepancies can be explained by adding a real part to the amplitude correlated with the difference between p-p and $\bar{p}$-p total cross sections. At present this hypothesis is being examined. For all these fits the corrections to the asymptotic formulas are negligible.

An interpretation was made of the observed resonance in the π-ω system at 1220 MeV (the B meson). It was pointed out that the dynamical assumption that the π-ρ-ω coupling was responsible for the interaction suggested a close analogy with the 3-3 resonance of the π-nucleon system. Simple considerations led to the hypothesis of a resonance in the 2^- state, of roughly the observed width. Subsequent work using a fully relativistic calculation of the effective range model confirmed the quantitative correlation between the shape of the observed resonance and the coupling constant, chosen to fit the width of the ω meson, and gave a more comprehensive discussion of the angular momentum assignment.

The problem has been examined of the angular and energy distribution of the 3-body final states resulting from isobar-type processes in which 2 of the 3 particles come from the decay of an isobar of known spin, mass, and width, and in which the contributions of several such isobar processes can interfere. An expression has been obtained for the relativistic matrix element for such a process for arbitrary spins of the particles and isobars, and a program has been written to compute the distributions, carrying out all helicity sums for any given case. This has been applied to generalization of previous calculations of others to higher angular momenta and to the analysis of the Λ-π-π decay of

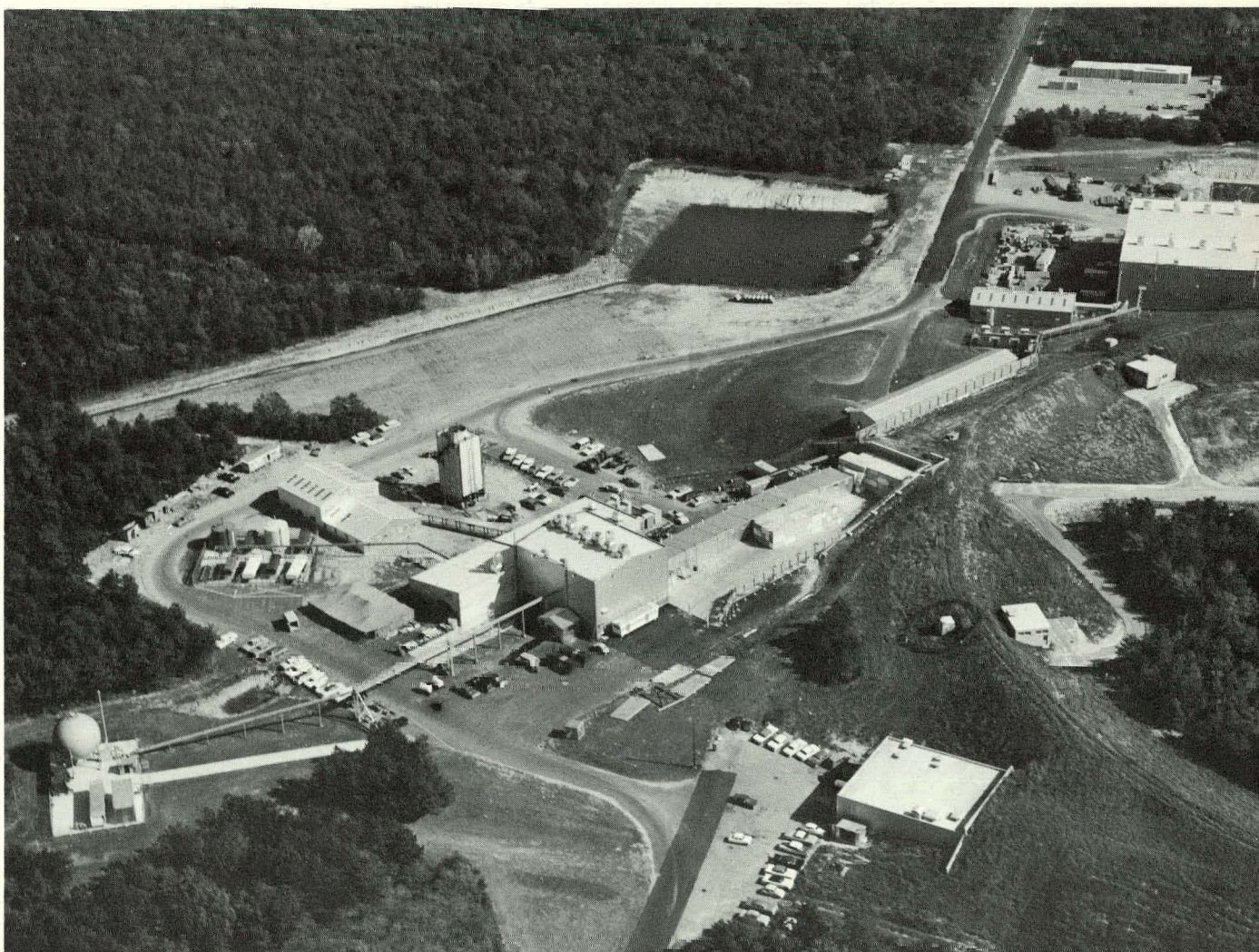
the 1660-MeV Y_1^* resonance, which gives possible evidence for a $D_{5/2}$ assignment.

Some of the principles of S-matrix theory are being applied to the study of nuclear forces below 350 MeV. The force is parameterized in terms of effective coupling constants between the nucleons and pion resonances, which are treated as "particles" exchanged by the nucleons. A new technique involving dispersion integrals of experimental data removes many of the ambiguities of previous efforts along these lines. In view of the rapid proliferation of the resonances this work is not conclusive, but a comparison with singlet p-p and p-n experimental data is encouraging.

The problem of mass relations of the strongly interacting particles (mesons and baryons) has been investigated. A number of linear mass relations have been obtained which connect the masses of various particles. These mass relations are partly based on the empirical observation of equal mass differences for different pairs of particles and on the existence of several sequences of particles with equal mass spacing. A simple mass formula for the strongly interacting particles is proposed which has been found to be in good agreement with mass values among the presently known particles and resonant states.

The International Conference on Fundamental Aspects of Weak Interactions was held at Brookhaven National Laboratory in September 1963. This conference was sponsored by the US AEC and IUPAP. It was organized and supervised by members of the BNL Physics staff and was attended by more than 140 physicists invited from all over the world, including the USSR. The sessions lasted 3 days with 16 invited talks and 24 contributed papers on all phases of the weak interactions.

Figure 11. Aerial view of the 80-in. bubble-chamber complex. Part of the AGS ring is visible at the right, under the mound of earth shielding. The separated beam emerges from the ring (right center) through a concrete shield wall and is guided into the large building in the center, which houses the 80-in. bubble chamber. The cooling tower is visible to the left of the main building. The low-pressure and high-pressure gas storage tanks for hydrogen are also at the left, in front of the service building. The spherical tank (lower left) provides high-pressure containment for the gaseous hydrogen when the liquid hydrogen in the chamber must be dumped.



80-in. Bubble Chamber

As reported last year, the Brookhaven 80-in. hydrogen bubble chamber was operated successfully on its first cool-down on June 2, 1963. This is the largest bubble chamber in the world, with an effective volume of 850 liters. An aerial view of the 80-in. bubble-chamber complex is shown in Figure 11. Since it first began operation, the 80-in. chamber has taken 566,736 stereo-triad photographs during 4 operating periods. About 18,000 photographs were used for engineering studies in order to understand chamber performance and to accumulate operating experience. Of the remaining pictures, 58,251 useful pictures (this number is normalized for proper number of beam tracks and desired purity of beam) were of 6-BeV/c π^- mesons for an experiment by a Brookhaven Bubble Chamber Group, 31,038 useful pictures were of 5-BeV/c π^- mesons for a Johns Hopkins University experiment, 10,000 useful pictures were of 8.5 BeV/c π^+ mesons and protons for a University of Pennsylvania experiment, and 60,000 useful pictures were of 7-BeV/c antiprotons for a cooperative experiment by Yale University and BNL. In addition, 127,603 useful pictures were of 5-BeV/c K^- mesons; in one of these the first example of Ω^- production and decay was observed. The chamber was in its fifth operating period at the end of fiscal 1964. Chamber reliability has been better than expected, and in general the over-all performance has presented no major difficulties. The most serious failure occurred on the third cool-down in November 1963, when a leak from atmosphere to vacuum occurred in the flexible metal bellows that isolates the chamber from the vacuum can. This leak terminated the third cool-down before any useful pictures had been obtained. The failure was repaired, and a secondary seal has been incorporated to prevent a reoccurrence. Another problem arose in connection with the retrodirectors ("coat-hangers") used for chamber illumination. This was solved by strengthening the mounting tabs and the support brackets. In May, with only 56 hr of downtime necessary for routine maintenance and repairs, chamber performance reached a level that made it possible to take 212,000 pictures, of which $\approx$175,000 were useful. A process control computer has been installed at the chamber and is aiding considerably in logging and recording. As more experience is gained it will take over some of the controls of the chamber. A continuing program of modification is being carried on with the aim of obtaining improved picture quality and reliability of operation. During the coming year it is anticipated that a soft glass window can be installed to decrease the distortion now introduced by the tempered window. Other improvements will require additional expanding pistons and a new oil-free vacuum pump system, bright-field modification to the illuminating system, and modification of the electronic controls.

High-purity beams in which the different kinds of particles are separated by means of electrostatic fields are brought to the chamber from the scattering target in the AGS primary beam by an array of 28 beam transport magnets. This array comprises focusing and deflecting magnets and is completely analogous to an optical system of lenses and prisms. In addition to the quadrupoles which perform the focusing function, the beam also contains sextupoles and octupoles for correcting aberrations (see Figure 12). Although this beam is much

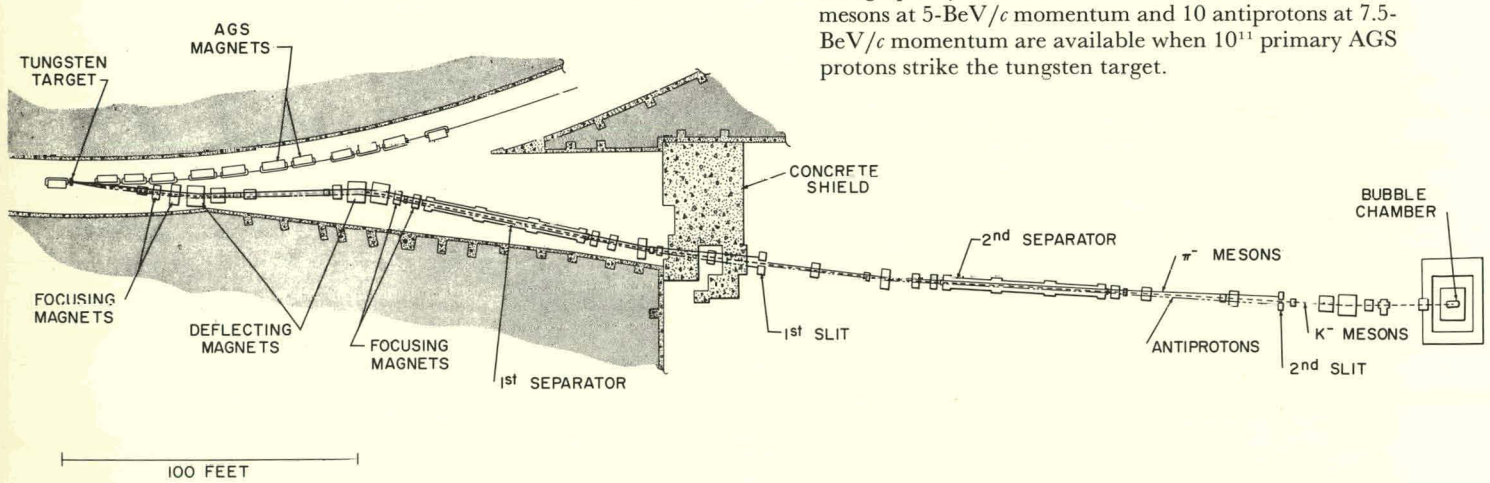


Figure 12. A sketch of the beam transport and separating system that provides beams of K mesons and antiprotons of high purity for the 80-in. bubble chamber. About 4 K^- mesons at 5-BeV/c momentum and 10 antiprotons at 7.5-BeV/c momentum are available when 10^{11} primary AGS protons strike the tungsten target.

more complex than those used for counter experiments, it is essentially semipermanent and is used for many different experiments over a long period of time. It has been operated successfully at momenta as high as 8.5 BeV/c. It provides up to 5-BeV/c K^- mesons with a purity of 95%. The intensity of the particles available at the bubble chamber is 4 K^- mesons or 10 antiprotons per 10^{11} protons/pulse in the internal beam of the AGS. Tuning this beam for the proper particle and momentum is a very complex process, but experience gained in the past year now enables this to be done more rapidly. After the beam has been tuned, a physicist must continuously supervise the operation in order to maintain optimum intensity. Instabilities in the high-voltage supply to the electrostatic separators considerably complicate the problem of directing the beam through the precise collimating slips. A program to improve this stability is under way.

Data Analysis

Following the first phases of research in a new high energy region the complexity of the experimental problems and setups gradually increases. A natural consequence is the need for more elaborate and sophisticated data analysis. Conventional measuring equipment has continued to bear the principal burden of bubble-chamber analysis efforts at BNL. Three Hermes automatic measuring machines are now in use for measurement of 80- and 30-in. chamber pictures. The two Mark II BNL measuring machines have been modified to accept 400-ft rolls of film and can now provide measurement facilities for the 35-mm Hough-Powell Flying Spot Digitizer (FSD). Design work has been completed for the modification of the Mark I BNL measuring machines to measure 3 views of 70-mm film from the 30-in. bubble chamber.

Of the 7 Vanguard scanning machines in operation, 3 can be equipped to rough-digitize 35-mm pictures, and 1 is a prototype for rough-digitizing machines to be constructed to handle the 80-in. bubble-chamber 70-mm film. Of the 6 BNL scanners, 4 have been converted to scan 2 views of 30-in. chamber pictures.

The automatic measuring system using the FSD has been used in the analysis of 3 experiments performed with the 20-in. bubble chamber. In the first experiment some 6000 2-prong events were measured, and in the second, a sample of $\approx$2000 4-prong events was measured. In the third experiment, 7000 2-prong, 2500 4-prong, and a few hundred single and double V events were measured.

The production measurement rate on the FSD *with* manual intervention at the IBM 7094 computer console for difficult cases (Manual Filter) has stabilized at $\approx$80 events/hr. Recent hardware and program developments have permitted the transfer of Manual Filter to an off-line CRT; the measurement rate for this mode of operation has been found in initial tests to be $\approx$110 events/hr. This rate is considered satisfactory for the system.

The rejection ratio for a second pass through the system, including rerough-digitizing at the scan table, is found to be comparable with that for the first pass. The 2-pass rejection ratio for the most recent 10,000 events is $\approx$3% for 2-prong events and $\approx$10% for 4-prong events. The 2-pass strange-particle rejection ratios observed are $\approx$20%, but a separate study is needed using an input sample richer in types of strange-particle events. All rejection ratios are believed to be susceptible of considerable further reduction, based on the observed rate of decrease over the past few months.

Bubble density is measured by the FSD for each track. An ionization-momentum χ^2 is calculated for each event in addition to the usual kinematic χ^2. Both χ^2's are used in event identification, and the human judgments involved in the use of these criteria have been incorporated in a computer program for event identification. The ionization-momentum χ^2 distribution suggests a measured ionization error only 1.15 times that expected from the statistics of bubble formation; however, further study is required.

For events occurring every few frames, each rough-digitizing scan table can supply events to the FSD at the rate of 15 events/scanner-hour. For events spaced $\approx$50 frames apart, the rough-digitizing can be done at the rate of $\approx$10 events/scanner-hour. (The latter figure was obtained in the course of doing remeasurements in cases in which the frame numbers containing the events were known.) In general, the original expectation of scanning rate, based on 1 min per frame scanned plus 3 min for rough-digitizing an event when found, seems to be reached or exceeded in practice. For 30 hr of FSD measuring time per week, 3 rough-digitizing scan tables, each manned 2 shifts per day, are required.

All the results given above were obtained with the 35-mm FSD. The 70-mm FSD transmitted its

first pictures to the 7094 computer just at the end of fiscal 1964. A moderate amount of work remains in operational testing of the equipment, especially the computer-controlled film transport. The modifications required in the FSD program HAZE are expected to be small for 30-in. but substantial for 80-in. bubble-chamber film.

The FSD computer-scanning programs are in the phase of small-scale production testing, as described in the section on Applied Mathematics.

To interpret measurements obtained with the data handling equipment, elaborate computer programs must be employed, specifically on the Brookhaven IBM 7094. Progress has been made in adapting programs to operations on the FSD and also to interpretation of data from 70-mm film, obtained with the 30- or 80-in. chambers. A new library program has been written and is being used at Brookhaven for collecting the data of kinematics programs for final physics interpretation, such as the preparation of histograms, effective mass distributions, scattergrams, etc.

A Brookhaven group has completed the construction of a flying spot scanner for the automatic measurement of spark-chamber photographs, as well as a preselector that enables an operator to instruct the scanner to measure only certain photographs which have been chosen by visual inspection. These two instruments have been used to study 150,000 spark-chamber photographs obtained in a K-p elastic scattering experiment performed at the AGS in the momentum range 3 to 5 BeV/c. The preselection showed that $\approx$⅙ of the photographs should be measured by the automatic scanner; the rate of preselection of photographs was 50/min. The automatic scanner measured a photograph in $\approx$25 sec; an analysis time of 2 sec per measured photograph was required by the IBM 7094 computer for processing (off-line) the magnetic tape output data from the scanner. The over-all analysis rate, $\approx$2 measured photographs per min, is $\approx$10 times faster than the rate attained when conventional scanning and measuring methods are used.

In connection with a p-p scattering experiment carried out by a Brookhaven group and described last year, it was pointed out that the group had designed a data analysis system permitting almost simultaneous collection and analysis of data, which greatly increased the efficient use of beam time. This equipment has now been much improved. The original digital data-handling system had 96 input bits and a 32-word memory and was limited to recording 32 events/pulse or $\approx$50,000 events/hr at the AGS. It became clear that this rate was far below that which might be required for many experiments. In collaboration with the Instrumentation Division staff, the group developed a high-capacity system having 48 input bits followed by a 4096 memory which could record several million 48-bit word events/hr. Two of these basic units could be used in parallel if desired. For their small-angle scattering experiment at the AGS (see above) the group used 192 input bits/event, which the data handler automatically broke up into 15 words of 48 bits each, stacking them successively in its 4096 memory. In this way they could handle more than a million events per hour. The data were gathered at a rate up to an order of magnitude faster than the Brookhaven Merlin computer, used on line, could process it. Thus Merlin was used only for sampling, and the remainder of the data was stored on magnetic tape and processed at the IBM 7094. This high-capacity digital data-handling system was designed to accept data bits from counter hodoscopes, wire chamber hodoscopes, sonic chambers, and any other digitizable electronic pulse-generating detectors while operating on line to a computer. These new techniques, which have already become quite important, should have an even greater impact on high energy physics experiments in the future.

Particle Physics Apparatus

Brookhaven high energy physicists, besides participating in experimental work at the AGS and the Cosmotron, devote much effort to the activities essential to the planning and execution of the particle physics program. Among other things, they are involved in the conception and design of new research facilities and instruments and data-handling methods and devices.

The 20-in. bubble chamber, which took 1.3 million photographs in fiscal 1964, will undergo major modifications in the coming fiscal year. A new chamber body has been designed to increase the size of the chamber to 31 in. A bright-field optical system will use Scotch light as the retrodirector. With this system the useful optical volume of the chamber will be 30 in. long by 9 in. high by 13 in. deep, equivalent to 57 liters, a large increase over the present dimensions of 17×8¾×10

in. for 24 liters. New magnet coils have also been designed which will produce a magnetic field of $\approx$24 kG, compared with the present magnetic field of $\approx$17 kG. New coil tanks and vacuum bell end sections are being constructed to accept the new magnet coil. A low-pressure deuterium gas storage facility will also be provided for this chamber.

The 30-in. bubble chamber took 1.4 million pictures during fiscal 1964. It also is being modified to use the Scotch light bright-field illumination. It will be shut down for a short period during the coming fiscal year to permit modification of the separated beam which provides the K mesons and antiprotons. This change will result in greatly improved purity of these particle beams.

The Brookhaven Bubble Chamber Group has devoted considerable time to the consideration of bubble chambers that may be needed for future experimentation, in particular for exposure to neutrino beams and to beams of particles at higher energies than have been explored so far. Because of the extremely small cross section of neutrinos, the size of a bubble chamber (which also acts as a target) is important, and because of the high complexity of interactions at very high energies the insertion of large metal plates for detection of unseen neutral particles is necessary. Possible chambers that have been under discussion (partially with members of the MIT staff) involve a 14-ft-diam liquid hydrogen bubble chamber and a 4-m-long propane (or other heavy liquid) chamber. Studies on the large hydrogen chamber are most advanced at this time, and a 14-ft-diam liquid hydrogen bubble chamber containing 40,000 liters of liquid, with 25,000 liters visible to 3 stereoscopic cameras, will be proposed for construction at Brookhaven. The chamber is to be expanded at least once a second by means of a new hydraulic control system, with the added possibility of multiple expansions for each AGS beam pulse. A 20,000-G magnetic field with vertical axis is to be provided. Wide-angle lens photography and retrodirective lighting are to be employed.

A new instrument, under development in collaboration with the Instrumentation Division, should increase the effectiveness and speed with which many types of high energy experiments can be carried out. The new device is a digitized discharge plane, sometimes called a wire discharge plane. Its principal use is to form magnetic spectrometers possessing an extremely useful combination of characteristics. Discharge planes, like spark chambers, locate a particle's trajectory by means of a discharge initiated by ions left in the gas, the discharge being produced by a short-duration voltage pulse. Unlike spark chambers, one of the elements between which the discharge takes place consists of fine wires spaced $\approx$1 mm apart, each passing through a small ferrite memory core. The discharge is located by a core or cores that have been "flipped" by the discharge current in the wire. Two crossed discharge planes will thus provide X and Y coordinates of the trajectory. The location of the flipped cores is determined by a fast readout system on line with a fast computer (see the section on Instrumentation). This system is capable of very high operating speeds. For example, a spectrometer system consisting of X and Y discharge planes totaling 10,000 wires can be read out in $\approx$500 μsec, corresponding to $\approx$1000 events per machine burst.

Magnetic spectrometers incorporating these planes can have the following characteristics:

1. Angular resolution, $\Delta\Theta$, $\leqslant$1 mR
2. Momentum resolution, dp/p, $\leqslant$1%
3. Solid angle of acceptance, $\approx 10^{-2}$ steradians (limited by magnet aperture)
4. Momentum acceptance of several BeV/c
5. Counting rate, $\approx$1000/pulse
6. Resolving time, $\approx$300 nsec

The combination of these characteristics makes the spectrometers unusually effective. The large solid angles permit complete kinematic analysis, as performed by bubble chambers, of a large class of events. The speed of the system and the fact that laboratory coordinates of the particle are immediately available mean that events can be selected on the basis of their kinematics (for example, selection of π^0 production events and rejection of $2\pi^0$ production events). High momentum resolution permits, for the first time, kinematic analysis of the highest AGS energy events. Finally, since the time-consuming process of extracting data from photographic film is eliminated, the analysis of the data can be achieved quickly. The rapid acquisition and quick availability of data will permit a shorter interval between successive experiments than is now possible. These devices have been tested at the Cosmotron and appear to be eminently practical. They should be useful in a wide variety of applications; for example, in β-ray

spectrometers, in beam profile indicators, and in the study of cosmic rays.

The program aimed at producing high magnetic fields is continuing. Some solenoids were wound of superconducting niobium-zirconium wire for particular application to certain experiments being conducted at the Laboratory. These solenoids were designed for fields of only 10 to 20 kG. To compare 3 promising superconductors (RCA Hastelloy ribbon on which Nb_3Sn is deposited, NRC niobium ribbon on which tin is reacted, and Westinghouse HI-120 wire), 3 similar solenoids are being wound to study the performance of these materials. The RCA material when wound on a solenoid with a ½-in. i.d. produced a magnetic field of 30 kG, which was its design field. This material was also wound in pancakes with a 1-in. i.d. using ¾-mil Mylar as turn-to-turn insulation. A number of pancakes were tried in two arrays, one in which the pancakes were clamped together with only Mylar sheet insulation between them, and a second in which the pancakes were clamped with spacers between them to permit more ready circulation of liquid helium. In the second case, the pancakes performed considerably better than in the first, in some instances carrying double the current. The Mylar insulation in these pancakes is being replaced by anodized aluminum to improve the low field stability of the RCA material. A large Nb-Zr solenoid designed for 50 kG with a 2-in. i.d. is also being wound to serve as a facility for testing samples of different superconductors.

Advanced Concepts

During fiscal 1963 many members of the Physics Department joined groups undertaking (1) a formal study of the design and experimental program for future accelerators (including one of 600 to 1000 BeV), (2) a study of storage rings for use with the AGS, and (3) consideration of possible modifications and improvements of the AGS. A special intensive summer study, representing the combined efforts of Brookhaven and specially invited university physicists, considered the usefulness of storage rings and experimental programs for super high energy accelerators. The question of storage rings had been discussed with considerable interest by the scientific community both in America and in Europe. The Ramsey panel had specifically recommended that Brookhaven National Laboratory undertake a study of this question. The technical findings have been published as Informal Report BNL 7534, *Proceedings of the 1963 Summer Study on Storage Rings, Accelerators, and Experimentation at Super High Energies.* This group also discussed the possibility of achieving a major increase in the intensity of the AGS by raising the energy of its injector. It soon became evident that the community of high energy physicists showed much more enthusiasm for this project than for storage rings. Increasing the present injector energy of 50 MeV by factors of 10 or more would give corresponding factors in ultimate AGS intensity. Other more immediate changes are expected to raise the present AGS intensity of $\approx 2\times10^{11}$ protons/sec to $\approx 10^{12}$ protons/sec. With a new 500-MeV linear accelerator and with a simultaneously proposed increase in AGS cycling rate, the intensity could reach 2×10^{13} protons/sec, higher by a factor of 100 than the present value. In addition, construction of a 500-MeV proton linac would provide a valuable extension of the accelerator art, and the new linac would be a model for the several-BeV injector for a 600 to 1000-BeV machine.

A separate study on beams and experiments for a high intensity AGS was therefore undertaken by the Physics Working Committee of the Super High Energy Policy Committee with the collaboration of high energy physicists from various universities and institutions as well as from the Brookhaven staff. The study, published as Informal Report BNL 7957, *Possible Beams and Experiments for a High Intensity AGS*, is divided into five sections: (A) Experimental Facilities and Targets, (B) Unseparated Beams, (C) Separated Beams, (D) Possible Experiments Involving the Weak and Electromagnetic Interactions, and (E) Possible Experiments Involving Strong Interactions.

Many experiments that are at present either completely impossible or in an unsatisfactory state could profit from an increase in the AGS intensity. The gain would be not only in event rate but also in quality. A list of these experiments would include low momentum transfer–weak interaction experiments, such as those on the leptonic decay modes of hyperons and mesons; high momentum transfer–weak interaction experiments, mainly concerned with neutrino and muon interactions; high momentum transfer–strong interaction experiments, including p-p scattering, neutron-anti-

neutron interactions, hyperon-neutron scattering, and π-p and K-p scattering; and experiments on the electromagnetic structure of strongly interacting particles.

NUCLEAR STRUCTURE

In the area of nuclear structure, work has continued on a large number of experimental and theoretical problems. Basically, the experimental program consists of the determination of (1) the various properties of nuclear energy levels – their energy, spin, parity, lifetime, and electromagnetic moment; (2) the characteristics of transitions between states of a nucleus or between neighboring nuclei; and (3) the parameters of nuclear reactions, where these are important in the interpretation of current theories of nuclear structure. The experiments fall into two general classes, those dealing with unstable (radioactive) nuclei produced at the 60-in. cyclotron or the Brookhaven Graphite Research Reactor (BGRR), and those concerned with the instantaneous products of nuclear reactions produced by charged particles or neutrons. The theoretical investigations cover a broad range, including fundamental aspects of nuclear structure, the development and interpretation of nuclear models, the treatment of extranuclear interactions such as internal conversion, and studies of nuclear reactions.

The method of precession of a γ-ray angular correlation pattern in an applied magnetic field has been successfully applied to the measurement of the nuclear g factors of excited states in Sc^{44} and Tm^{169}.

In Sc^{44}, a 146-keV excited state decays to the Sc^{44} ground state via a cascade of two successive γ rays with energies of 78 and 68 keV. The 68-keV state has a measured half-life of 1.53×10^{-7} sec. With the parent Ti^{44} source in dilute HCl solution, the angular correlation between the two γ rays is found to be undisturbed for at least 1 μsec. The g factor of the 68-keV state has been measured by perturbing the directional correlation with a magnetic field of 7550 G applied perpendicular to the γ-ray detection plane. The Larmor precession frequency was measured for an angular separation of the detectors of 135° by observing the resulting oscillations about the exponential decay curve with a time-to-amplitude converter. The behavior of the time spectrum with applied magnetic field (up or down) is shown in Figure 13. With each counter detecting both γ rays with equal efficiency, the unperturbed time spectrum ($B=0$) is symmetric about $t=0$. With an applied field, the oscillations vary continuously through $t=0$ and

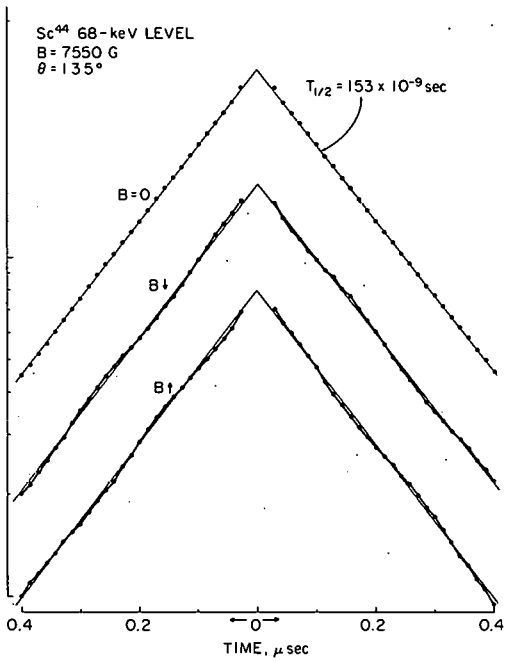


Figure 13. Decay curves showing the precession of the angular correlation of the 78- and 68-keV γ rays of Sc^{44} in an applied magnetic field. The upper curve shows the exponential decay of the 68-keV level at zero field. The middle and lower curves show the oscillation of the angular correlation about the exponential decay curve for the two directions of the applied field.

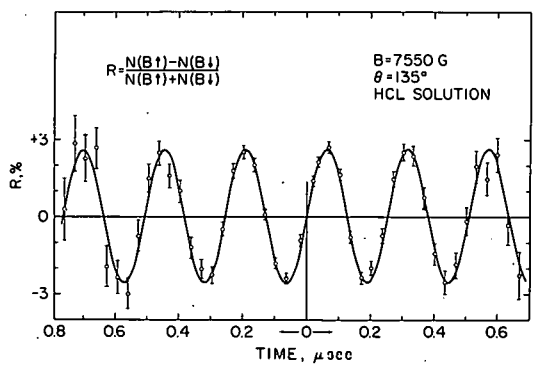


Figure 14. The net effect of the precession of the γ-ray angular correlation pattern in Sc^{44}. The counting rate difference (field up minus field down) divided by the counting rate sum (field up plus field down) is plotted against delay time.

can be followed for ≈ 5 half-lives on each side of $t=0$ without visible amplitude attenuation. The oscillations are more clearly exhibited in Figure 14, in which the counting rate difference (field up minus field down) divided by the counting rate sum at a particular delay time is plotted against delay time. The observed precession frequency and phase at $t=0$ gives a value for the g factor of the 68-keV state in Sc^{44} of $g=0.342\pm 0.006$.

A g-factor measurement has also been made on the 138-keV $7/2+$ member of the $K=1/2$ rotational band in Tm^{169} by an integral-type method made necessary by the short lifetime ($T=0.42\times 10^{-9}$ sec) of the state. The adoption of a paramagnetic correction factor $\beta=5.56$ appropriate for a thulium ion in a $+3$ charge state gives a value for the g factor of the $7/2+$ state of $0.428+0.031$.

Mössbauer-effect studies concerned with the recoil-free emission and resonant absorption of nuclear γ rays emitted by nuclei of atoms bound in solids have continued. The effect has been observed for the 90-keV transition in Ru^{99}. The combination of a resonant absorber of metallic iron into which was incorporated 2.3 atom % ruthenium enriched in Ru^{99} and a single-line source of Rh^{99} in Ru metal (both source and absorber held at a temperature of 5°K) clearly showed the components of the magnetic hyperfine spectrum. This spectrum, shown in Figure 15, is consistent with the following interpretations:

(a) The 90-keV state in Ru^{99} has spin $3/2$.
(b) The 90-keV transition to the spin $5/2$ Ru^{99} ground state is a mixed $M1+E2$ transition with $M1/E2=0.4\pm 0.1$ as deduced from intensities of the component lines in the hyperfine spectrum.
(c) The ratio of the magnetic moments of the excited state and ground state is $\mu_e/\mu_g=0.46$.
(d) With a value of -0.6 nuclear magnetons for the ground-state moment, the magnetic field at the Ru^{99} nucleus is 5×10^5 Oe.

Positrons annihilating in amorphous solids and plastics have been found to exhibit a third component τ_i of lifetime intermediate in value between the previously known components τ_l (usually a few $\times 10^{-9}$ sec) and τ_s (a few $\times 10^{-10}$ sec). The exact values of the lifetimes and intensities vary from substance to substance. A certain correlation between τ_l and τ_i seems to exist in the sense that a material exhibiting a relatively long (or short) τ_l will generally exhibit a relatively long (or short) τ_i. This pattern of behavior suggests a common feature in the mechanism that determines τ_l and τ_i.

A search has been carried out for charge $e/3$ particles (quarks) in the cosmic radiation at sea level. Pulses from a counter telescope (7 counters in a vertical array, plus a large anticoincidence guard counter to veto signals originating in Lucite light guides) have been exhibited on a dual-beam oscilloscope and photographed in a search for events which show $\approx 1/10$ of the minimum ionization of a particle with charge e in all 6 displayed counters of the 7 in the coincidence counter telescope. No events satisfying the proper criteria were found during an interval in which $\approx 3\times 10^5$ minimum ionizing muons triggered the counter telescope.

A search has been undertaken for double internal conversion in radioactive decay. This was done by counting coincident electron pairs of appropriate total energy entering selected gaps of an Orange β-ray spectrometer equipped with a split detector. From a source of In^{114m}, two coincidence groups are observed, with total energies corresponding closely to those expected for "KL" and "LL" double conversion parallel to the 191-keV isomeric transition. However, investigation of the angular distributions between these coincident electrons and the source orientation indicated that these groups arise from elastic (Møller) scattering of the single K- and L-shell conversion electrons of the isomeric transition on electrons in the 6000-Å aluminum source backing. This scattering mechanism cannot produce coincident pairs with energies corresponding to "KK" double conver-

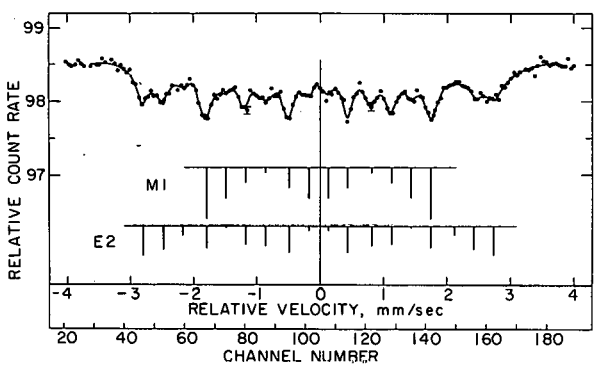


Figure 15. Mössbauer absorption spectrum of the 90-keV transition in Ru^{99} for a single-line source of Rh^{99} in Ru metal and an absorber of 2.3 atom % Ru^{99} in Fe metal. Both source and absorber were at a temperature of 5° K.

sion, and, in fact, no significant coincidences of this type are observed. If isotropic energy and angular distributions for the unobserved processes are assumed, the present experiment indicates that $KK/K<5\times10^{-4}$, where K stands for the intensity of single K conversion of the isomeric transition. This limit is consistent with the upper limit on double photon emission $\gamma\gamma/\gamma<3\times10^{-5}$ already known for this transition. Both of these upper limits are distinctly less than current expectations.

Until recently the chief obstacle to coincidence studies of low energy internal conversion electrons from nuclear transitions has been the inability of electron detectors suitable for coincidence work, usually plastic scintillators, to detect electrons with energies $<\approx20$ keV. This problem has been met at Brookhaven National Laboratory with the development of techniques for the preacceleration of electrons in a β-ray spectrometer. The method is particularly useful because low energy transitions in nuclei are usually highly converted, so that the observation of internal conversion electrons may often be the only feasible way to study them. In this technique thin sources of the element (or isotope) under study are prepared by electron beam bombardment and activated in the BGRR. Their

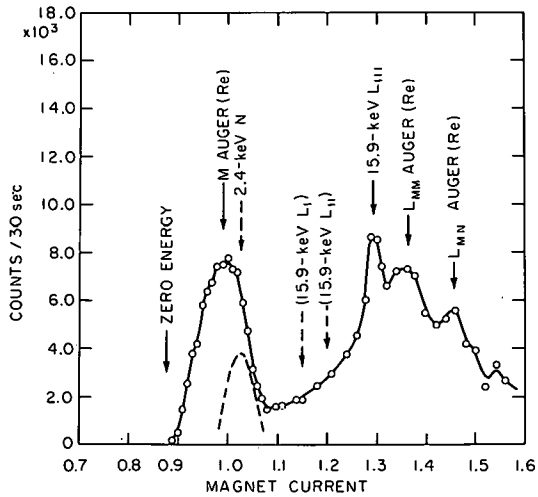


Figure 16. The low energy electron spectrum of Re^{188m} taken in a Gerholm spectrometer at 5-keV preacceleration. The lower peak consists of two unresolved components: the M Auger electrons of rhenium and the N internal conversion electrons of the 2.4-keV nuclear transition in Re^{188m}. The upper, partially resolved peak consists of the L_{III} internal conversion electrons of the 15.9-keV nuclear transition in Re^{188m} and the L_{MM} and L_{MN} Auger electrons of rhenium.

electron spectra are obtained with the help of a Gerholm electron-electron coincidence spectrometer. The resolution of the instrument is typically 3% at 3% transmission. The electrons are detected by plastic scintillators. In order to extend the energy range of the scintillators the source is held at a potential negative with respect to the spectrometer which can be varied between 0 and 25 kV. Thus the electrons are accelerated before the magnetic momentum selection takes place.

The decay scheme of the isomer Re^{188m} (18.7 min) was studied with this arrangement. Two hitherto hidden isomeric transitions of 2.4 and 15.9 keV were detected.

Figure 16 shows the low energy electron spectrum of Re^{188m} taken at 5-kV preacceleration. L and M conversion lines of the 15.9-keV transition and the N conversion line of the 2.4-keV transition are seen. The L_{III} line of the 15.9-keV transition is partly resolved from the L Auger spectrum. The low energy peak was found to consist of two components by studying the γ spectrum in coincidence with the left part of the line (Figure 17, curve A: the 92- and 105-keV peaks are approximately equal) and with the right part of the line (curve B: the 105-keV peak is considerably more prominent than the 92-keV peak), which made it possible to identify the left part with the M Auger spectrum and the right part with the 2.4-keV N line. The energy values given are based on very precise crystal spectrometer results on the 63-, 92-, and 105-keV lines, obtained by a group in Munich. Figure 18 gives the decay scheme of the isomer, which is of interest in the study of the structure of odd-odd nuclei in the transition region between strongly deformed and spherical nuclei.

In the course of studies of thermal neutron capture γ rays carried out at Brookhaven National Laboratory, new data on the intensities of the primary γ rays, i.e., those that de-excite the state formed in neutron capture, have been obtained for a number of isotopes. A comparison has been made of the strengths of those transitions identified as having $E1$ multipole order with the spectroscopic factors for the (d,p) reaction on the same target leading to the same individual final states. Some interesting results are found for $l=1$ final states in odd-neutron nuclei in the $A\approx60$ region. Certain states near the ground state which are strongly excited in the (d,p) reaction (those having large components of single-particle p state in their wave functions) also have large $E1$ strength from the capturing state. In the region between 1.5 and

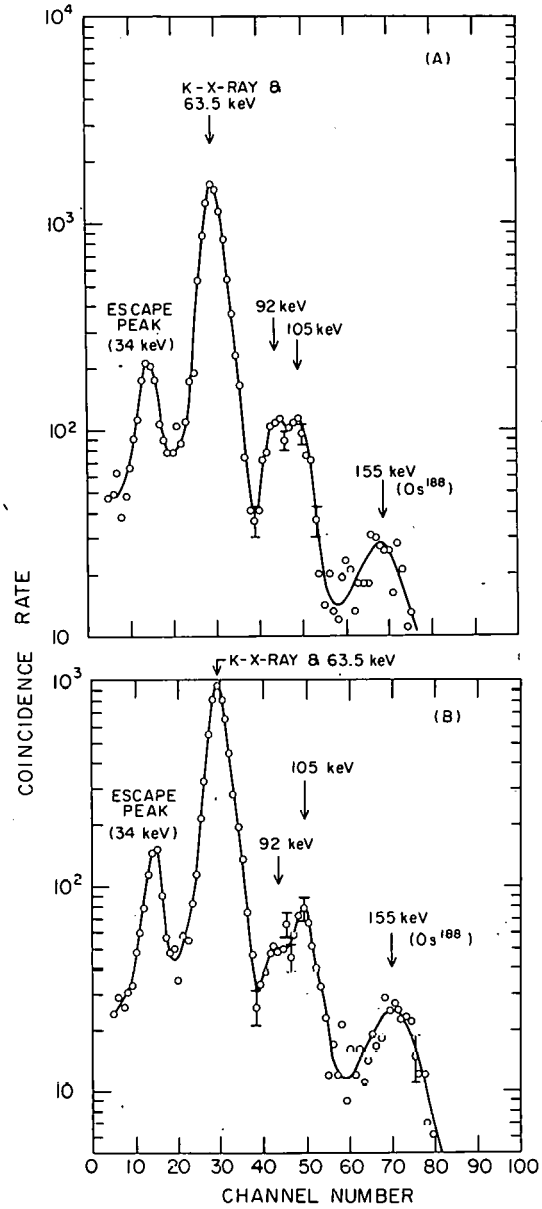


Figure 17. The γ rays of Re^{188m} coincident with the two components of the lower energy peak in the electron spectrum shown in Figure 16. Curve *A* shows the γ-ray spectrum coincident with the lower component of the peak (Auger electrons); curve *B* shows the γ-ray spectrum coincident with the upper component (*N* internal conversion electrons of the 2.4-keV transition). The 105-keV transition is seen to be enhanced in curve *B*.

Figure 19. A comparison of the strengths of transitions to individual final states in Fe^{57} for the (n,γ) and (d,p) reactions. The upper curve shows the reduced transition probabilities $B(E1)$ of γ-ray transitions from the state formed by neutron capture to lower-lying levels in Fe^{57}; the lower curve shows the weighted spectroscopic factors $(2J+1)S$ for levels of Fe^{57} populated in the (d,p) reaction.

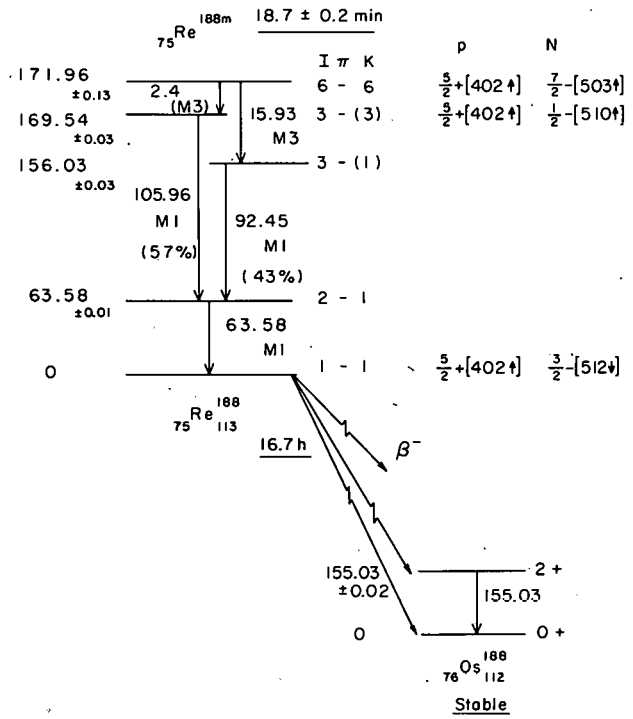
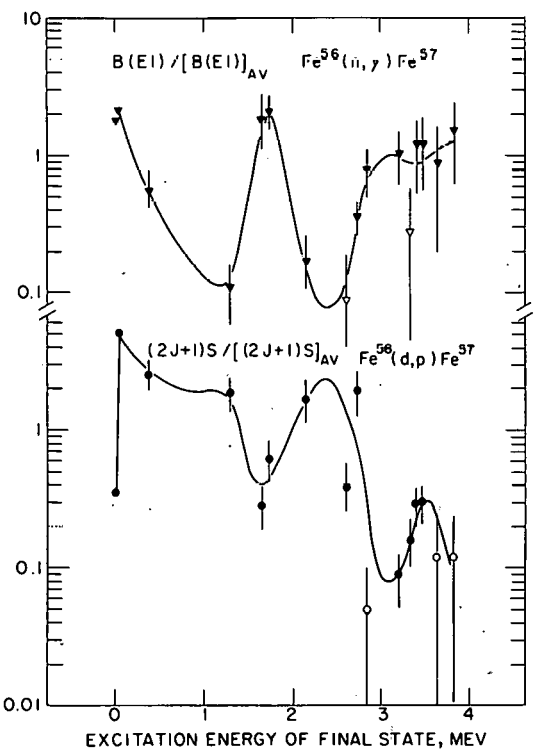


Figure 18. The decay scheme of Re^{188m}. The energies of the excited states are shown to the left of the diagram, and the spin (I), parity (π), and projection of the intrinsic spin on the axis of deformation (K) are shown to the right. On the far right the Nilsson quantum numbers for the individual proton and neutron states are given.



4 MeV, however, there are groups of states that have large $E1$ strengths but small spectroscopic factors; in fact, an anticorrelation exists between the (d,p) and (n,γ) transition strengths to individual levels. Previously it had been believed that the two reactions were to some degree correlated. The data for the (n,γ) and (d,p) reactions on Fe^{56} are shown in Figure 19. From the pattern (observed in coincidence measurements) of the γ-ray decay to lower states of the states strongly fed in the (n,γ) reaction but not in the (d,p) reaction, it is concluded that many of these states are seniority-three excitations (2-particle, 1-hole states). About the right number and type of seniority-three states are expected in this energy region. The $E1$ transitions in neutron capture thus come from seniority-three (or , in some cases, perhaps seniority-five) components in the capture state wave function. That is, these transitions are not due to direct capture, nor to decay of a fully developed compound nucleus. They seem to be due to the effects of the "intermediate resonances" so widely discussed recently, and are perhaps among the most convincing experimental confirmations of the "intermediate resonance" hypothesis.

Some data are also available on the (p,p') reaction on Fe^{57} (in which the energy of the outgoing proton fixes the final nuclear state of the reaction before γ-ray emission). There is some correlation between the (n,γ) and (p,p') strengths, except for the 0.37-MeV state. That state is perhaps excited in the (p,p') reaction through its collective components.

A number of lithium-drifted germanium γ-ray detectors have been successfully fabricated by the Nuclear Structure Group. Typically, these detectors have sensitive depths of 4 to 7-mm thickness, with areas of 2.5 to 9 cm^2. The best resolution attained is <5 keV. These devices are now in routine use for investigations of complex γ-ray spectra from unstable nuclei, charged particle reactions, and thermal neutron capture.

In the Van de Graaff research program the problem of the parity of Be^{11} has been solved in two ways. This radioactive nucleus decays partially by allowed β-ray transitions to a state at 7.99 MeV and to one of two 6.76 to 6.81-MeV doublet levels in B^{11}. Prior to this work the parity of the 7.99-MeV state was not known. Although the upper and lower members of the 6.8-MeV doublet in B^{11} were known to be of even and odd parity, respectively, it had not been established to which member of the doublet the β decay takes place. In one experiment, through measurements on radiations from the $Be^9(He^3, p)B^{11}$ reaction with a magnetic pair spectrometer, it has been shown that the γ-ray transitions from the 7.99-MeV state to the ground state and to the 2.13-MeV state of B^{11} (both known to have odd parity) are both electric dipole. This requires that the 7.99-MeV state have even parity, and, in turn, that Be^{11} must have even parity. In the other experiment a lithium-drifted germanium γ-ray detector was used to demonstrate that Be^{11} decays to the upper, or even-parity, member of the 6.8-MeV doublet, which again requires even parity for Be^{11}. Although the original shell-model prediction for the spin-parity of the Be^{11} ground state was $\frac{1}{2}-$, a more refined calculation has recently been carried out by a group in Israel according to which the $\frac{1}{2}-$ and $\frac{1}{2}+$ states of Be^{11} should be inverted. The present result therefore confirms the new theoretical prediction that the Be^{11} ground state should be of even parity.

A search has been made for double γ-ray emission in competition with the electric monopole pair emission from the 0+, 6.06-MeV, first-excited state of O^{16}. The state was excited in the $F^{19}(p,\alpha)O^{16}$ reaction, and the radiations were detected in two 5×5-in. NaI crystals. By means of a 2-dimensional pulse-height analysis technique an upper limit of 1.1×10^{-4} was placed on the intensity of double γ-ray emission relative to the normal mode of nuclear pair emission. This limit is 20 times smaller than a positive value for the effect that has been reported in the literature. There is now no known case in which double γ-ray emission has been observed and reconfirmed.

Detailed studies have been made of two energy levels in B^{10} at 4.77 and 5.16 MeV which are energetically unstable against α-particle emission. The states were excited in the $B^{11}(He^3,\alpha)B^{10}$ reaction in a thin, self-supporting B^{11} target. Alpha particles, recoil nuclei, and γ rays were detected in coincidence. In a variety of experiments it was shown that the 4.77-MeV level decays almost entirely by α-particle emission but that it has a partial γ-ray branch with a relative intensity of 2.5×10^{-3}. On the other hand the 5.16-MeV state decays 85% of the time by γ-ray emission and the remainder by α-particle emission. In separate experiments on the $Li^6(\alpha,\gamma)B^{10}$ reaction it was established that the γ-ray partial width of the 4.77-MeV level in B^{10} is 0.056 eV. By combining the two experiments on this level, the partial α-particle width of the 4.77-MeV state is found to be

$\approx$27 eV, which is more than twice as great as the Wigner limit. The reason for the abnormally large width is not yet understood.

At the 60-in. cyclotron the investigation of final-state interactions in few-nucleon systems, carried out in collaboration with members of the Chemistry Department and guests from Bell Laboratories, has continued. The reaction $p(d,2p)n$ has been investigated. The energies of coincident pairs of protons were registered by two semiconductor particle detectors. The correlated energy information was stored on-line in a small digital computer programmed as a 2-dimensional pulse-height analyzer. The computer was also used to generate curves showing relevant kinematic and theoretical information presented in the same display format as the experimental data for rapid comparison during the experiment. Figure 20 shows cathode-ray-tube displays of experimental data in a 64 $\times$64-channel array. T_3 and T_4 are the kinetic energies of the coincident recoil protons. The two pronounced bumps on the curve at high T_3, low T_4, and at low T_3, high T_4, represent the formation of quasi-deuterons in the singlet state. The bump at low T_3, low T_4 is due either to the low energy p-p interaction or to a direct knockout feature of the reaction mechanism. Such direct knockout features were found to be very prominent in a study of the reaction $d(d,pd)n$. Coincident proton-deuteron pairs were measured with the same technique as above. No strong peaks were expected in the experimental data since there are no strong resonances in the possible intermediate systems $(d+p)$ and $(d+n)$, and the formation of the singlet deuteron is forbidden by isospin conservation, since it is $I=1$ and all the other particles are $I=0$. The experimental data for one pair of detector angles are shown in Figure 21. The two p-d coincidence curves are clearly seen. Several straight lines and spots due to random coincidences and 2-body reactions are also visible. The outer curve, in which the deuteron energy is T_3 and the proton energy T_4, has a very strong peak which is seen as a faint broad curve of white dots above the black part of the data curve. Measurements at many angles show that this peak is not a final-state interaction in any system, although it cannot be distinguished from such by a measurement at a single pair of angles; rather, it always appears when the laboratory momentum of the unobserved neutron is very small. Although this peak is several MeV broad in the T_3 or T_4 coordinates, it is much sharper in the laboratory neutron energy T_5. Most of the reaction cross section appears in a region where T_5 is $<$200 keV. The strong peaking at low values of T_5 is a general feature of the various other reactions that have been investigated. It is attributed to a direct knockout process, and for this reaction it may be shown that the shape of the experimental peak is quantitatively described by a simple plane-wave knockout calculation, based on the assumption that the cross section in the region of the knockout "pole" is dominated by the effect of small momentum transfer to the neutron.

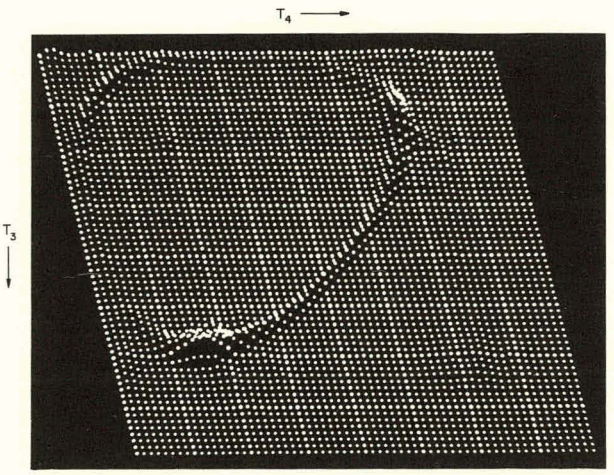


Figure 20. Cathode-ray-tube display of the energy distribution of the coincident recoil protons from the $p(d,2p)n$ reaction. The coordinates T_3 and T_4 are the kinetic energies of the recoil protons. The two pronounced bumps on the curve at high T_3, low T_4, and at low T_3, high T_4 represent the formation of quasi-deuterons in the singlet state.

The reactions $d(\mathrm{He}^3,pt)p$, $d(\mathrm{He}^3,p\mathrm{He}^3)n$, and $d(\mathrm{He}^3,pd)d$ have been investigated in a search for final-state interactions in the $(p+t)$, (He^3+n), and $(d+d)$ intermediate systems. These final-state interactions would be due to particle unstable excited states of He^4. These investigations have thus far identified two excited states in He^4. One is at an excitation of 19.99$\pm$0.02 MeV with a width of 0.1 MeV. This state, being below the He^3+n threshold, can only appear in the $t+p$ breakup. The second state is at an excitation of 21.2$\pm$0.2 MeV, with a width of 1.2 MeV, and is observed to decay by both proton and neutron emission. These two excited states have been measured at many angles and are observed to be genuine levels of He^4 in the sense that their energies and widths are independent of the angle of observation.

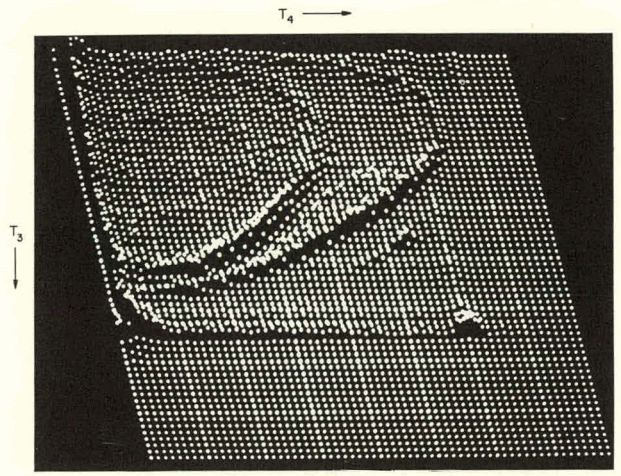


Figure 21. Cathode-ray-tube display of the energy distribution of the coincident recoil deuterons and protons from the $d(d,pd)n$ reaction. The coordinate T_3 is the kinetic energy of the recoil deuteron, and T_4 is the kinetic energy of the recoil proton. The very strong peak on the outer curve corresponds to a knockout process in which there is a high probability that the recoil neutron will possess a very small kinetic energy.

The previously unreported 2-neutron pickup reaction $Mg^{26}(He^4,He^6)Mg^{24}$ has been investigated. A scattering chamber was used in conjunction with a counter telescope having a thin dE/dX counter, an E counter (sufficiently thick to stop all He^6 particles), and a veto counter in anticoincidence to reject all particles that were able to penetrate the first two counters. The detector system was able to discriminate He^6 particles in a He^4 background 100,000 times stronger. Figure 22 shows a typical mass spectrum as observed with the system.

A number of levels of Mg^{24} were studied with the $Mg^{26}(He^4,He^6)Mg^{24}$ reaction and the results compared with similar studies on the $Mg^{26}(p,t)Mg^{24}$ reaction. The main findings of interest to nuclear structure are: unnatural parity states are more strongly excited in the (He^4,He^6) reaction than in the (p,t) reaction; the angular distributions oscillate strongly and indicate a direct process which may be easily analyzed; and the ground and excited states are excited with comparable strengths, while in the (p,t) reaction only the ground and low-lying states are strongly excited. The 3-neutron pickup reaction $Mg^{26}(He^3,He^6)Mg^{23}$ has also been observed.

Several advances in nuclear theory have been made during the year. The calculation of the properties of spherical nuclei from a detailed shell

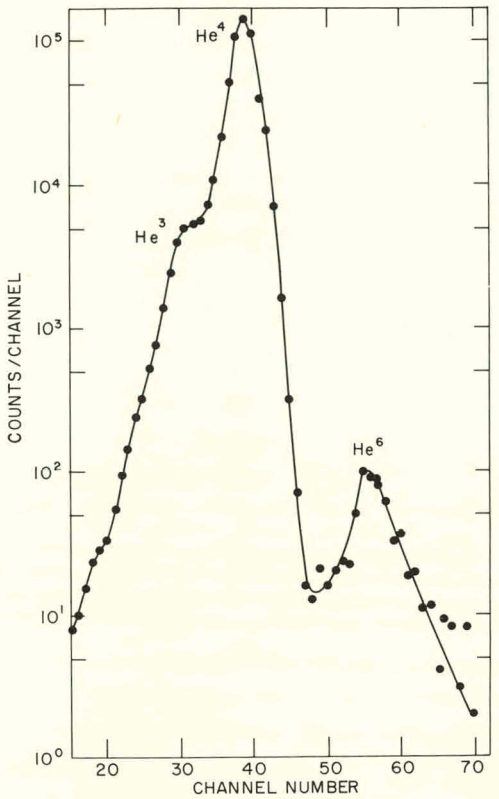


Figure 22. The mass spectrum of recoil particles registered by a telescope of semiconductor E and dE/dX counters in anticoincidence with a veto counter, in a study of the $Mg^{26}(He^4,He^6)Mg^{24}$ reaction.

model is a subject of general interest. The Belyaev and Zelevinski perturbation method has been used to calculate the smaller deviations from harmonicity; it is an expansion in $1/\Omega$, where Ω is the number of available shell-model states. Since the number is not a constant in the underlying Bardeen, Cooper, and Schrieffer (BCS) method, the number dispersion, as well as the usual number spuriosities, appears also in this method.

However, since the expansion is explicit in $1/\Omega$, it is possible, first, to write the number operator explicitly up to the desired order, and second, to make explicit to this order the dependence on the number dispersion. It is not possible to actually diagonalize the number operator without violating the expansion. However, since the number dispersion is explicit, it is straightforward to construct the excitation operators so as to commute with the number operator, and thus to insure that the excitations contain no spurious parts corresponding to changes in the number of particles.

In this way the recent results of Nogami and of Nilsson on the effect of number dispersion in the calculation of the ground-state energy have been verified, and it is established that their procedure holds in the leading order and the next order. Further, the spurious states having to do with number dispersion are explained and removed. Finally, higher orders of perturbation theory can be computed free from spurious contributions.

The Hartree-Bogolyubov self-consistent field equations in a rotating reference frame have been studied. The rotational energy has been found in the form of a series in the angular momentum J,

$$E_J=\frac{\hbar^2}{2\mathcal{J}}J^2+BJ^4 .$$

Of particular interest is the B coefficient. With pairing plus quadrupole-quadrupole forces taken into account, the B coefficient can be decomposed as follows:

$$B=B_{\text{V.R.}}+B_{\Delta}+B_{\text{Coriolis}} ,$$

where $B_{\text{V.R.}}$ corresponds to a centrifugal stretching of the mass quadrupole moments due to rotation and has exactly the form, but not the hydrodynamical values, required by the Bohr-Mottelson model for the vibration-rotation coefficient; B_{Δ} is a contribution arising from the change in the energy gap for fixed quadrupole moment; and B_{Coriolis} is a pure fourth-order cranking model term. Numerical calculations are being made. The rotational phase transition predicted by Mottelson and Valatin is also being studied by this method.

First-order corrections to the distorted-wave Born approximation (DWBA) amplitude for (d,p) reactions have been shown to occur. These correspond to excitation of the target nucleus by the outgoing proton, with subsequent capture of the stripped neutron to form the residual nucleus. These corrections have been included in the theory in such a way as to facilitate computation by high-speed computers. Calculations of the first-order correction terms indicate a 10% increase in the total cross sections for the reactions $O^{16}(d,p)O^{17}_{0,0.87}$ and $Ca^{40}(d,p)Ca^{41}_{0}$ at $E_d\approx 5$ MeV. A computer search is now being made for the best optical model parameters needed to fit the $Li^6(d,p)Li^7_{4.64}$ reaction. The DWBA amplitude vanishes for this latter case, and only the correction terms will contribute to the angular distribution.

Values of the quadrupole antishielding factor γ_∞ have been obtained for the Al^{3+}, Co^{+}, I^{-}, Pr^{3+}, and Tm^{3+} ions. From the density of induced quadrupole moment as a function of distance from the nucleus, values of the atomic shielding factor R have been calculated for the $4f$ electrons of praseodymium and thulium. An estimate of the second-order effects on γ_∞ for the Cl^{-} ion has been obtained by including the effect of the induced quadrupole moment in the calculation of γ_∞. The value of the second-order term is found to be only $\approx 10\%$ of the dominant term of γ_∞, which is calculated by first-order perturbation theory.

NEUTRON PHYSICS

At the BGRR a continuing program of investigations of the scattering of very slow or "cold" neutrons by liquids and solids is being carried out. Recently the research effort has been directed toward understanding the interaction of cold neutrons with a system of rotating molecules in condensed matter. Two guest scientists from the Institute of Nuclear Physics in Krakow, Poland, participated in one phase of this work. The molecular rotations of CH_4 in gas, liquid, and solid form were studied. In the gaseous form good agreement exists between experiment and theories based on the Sachs-Teller mass tensor description of the interaction of the neutron with a freely rotating molecule; however, as the gas condenses, first to liquid and then to solid phases, the agreement with mass tensor theories vanishes. Experimentally, the "effective mass" of the rotating molecule increases as the molecules condense from gaseous to liquid or solid phases. The study was extended to provide a comparison with liquid CH_4 of substances (CH_3I, NH_4ClO_4, and NH_4PF_6) which are known from other physical data to contain freely rotating groups of CH_3 and NH_4 molecules. The spectra of inelastically scattered neutrons from all these substances showed similar deviations from theory. These measurements provide an empirical means for determining the freedom of rotation for CH_3 and NH_4 molecules in liquids until some better theoretical framework is evolved.

At the Brookhaven fast neutron chopper, improved measurements of cross sections in the rare earth region have been carried out in a search for evidence for a J-dependence of the S-wave strength function. A plot of the compound nucleus cross section for low energy neutrons (or equivalent S-wave strength functions) as a function of mass number shows the typical peaks and valleys predicted by the optical model. There appears on such a plot, however, considerably more scatter of

experimental points than expected. This has led to the speculation that the optical model potential should include a term depending on the J values of the compound states formed.

Recent improvements in the fast chopper facility have made it possible to measure strength functions more accurately by determining the energy variation of the total cross section in the region of 1 to 10 keV where the individual resonances are not resolved. These improvements include extension of the flight path from 20 to 30 m, a larger detector bank, and an improved data-recording and analysis system built around a small, on-line computer.

With this system the S-wave strength functions of odd-A isotopes of gadolinium and dysprosium have been measured. In each case an average is taken over two spin systems, $J=I\pm\frac{1}{2}$, and the analysis shows that if a strength function proportional to J is assumed, the average strength function will be proportional to $2I+1$. For Gd^{155} $I=\frac{3}{2}$, and for Gd^{157} $I=\frac{1}{2}$. On the other hand, Dy^{161} and Dy^{163} both have $I=\frac{1}{2}$. The results of the measurement are summarized below.

Isotope	I	Strength Function $(\Gamma_n^0)/D$
Dy^{161}	$\frac{1}{2}$	1.95 ± 0.14
Dy^{163}	$\frac{1}{2}$	1.92 ± 0.16
Gd^{155}	$\frac{3}{2}$	1.52 ± 0.09
Gd^{157}	$\frac{1}{2}$	1.49 ± 0.09

The conclusion is that there is no evidence for a J-dependent term in the optical model potential.

During the past several years, investigations have been made of the γ-ray spectra originating with the capture of neutrons in resonance levels of the compound nucleus. One very obvious conclusion from these measurements is that the capture γ-ray technique permits the detection of very weak S- and P-wave levels that are difficult or nearly impossible to observe in transmission. However, conventional methods of obtaining the Breit-Wigner parameters of resonance levels are based on transmission (total cross section) measurements, and hence are not directly applicable in the case of capture γ-ray detection.

The problem of obtaining the Breit-Wigner parameters from capture γ-ray measurements alone was therefore investigated. An extension of the self-indication method first proposed by Bethe was arrived at. It consists of using a resonance detector of a given sample thickness and interposing various thicknesses of the same material as resonance absorbers. Ratios of counting rates with and without absorbers are compared with those calculated numerically by means of a program written for the IBM 7094. The program computes these ratios as a function of $n_T\sigma_0$ and Δ/Γ, where n_T is the number of atoms/cm^2 of the transmission sample and the other symbols are conventional. The combination of thin and thick sample measurements yields the Breit-Wigner parameters σ_0 and Γ. A calculation has also been developed to correct for multiple scattering in the measurements. The method has been applied to data obtained at the General Atomic linac for the eight strong low energy levels in Th^{232} in order to obtain an accurate value for the resonance absorption integral.

For some time data collected in the slow and fast chopper time-of-flight experiments at the BGRR have been accumulated in a time-shared SDS 910 computer system. This time-sharing process has recently been extended so that the computer may be utilized for computational purposes not necessarily directly related to the events being processed. Thus, the present system performs three functions at the same time: (1) processing and storage of fast chopper data, (2) processing and storage of slow chopper data, and (3) performance of routine computational jobs. The data rates are such that $\approx$99.7% of the computer time is available for function (3). The computer will be used in writing and debugging programs for multiparameter experiments at the High Flux Beam Research Reactor (HFBR) and for routine data transformations such as calculation of cross sections and transmissions.

The construction and testing of the major components of the new cold neutron facility and the new fast chopper, to be installed at the HFBR, is proceeding, and both facilities are expected to be in operation late in 1964. The cold neutron facility, intended for studies of the scattering of long-wavelength neutrons by condensed matter, is a neutron chopper system employing 3 rotors, 1 with a vertical axis and 2 with horizontal axes, each $\approx$1 m in diameter. This system combines high neutron intensity with variable wavelength and time resolution. The rotors will be driven at 15,000 rpm by synchronous motors with stringent conditions maintained on the relative phase of the rotors. The fast chopper, which will be employed in studies of the interaction of neutrons with nuclei in the resonance region, consists of a single rotor of heavy material which will rotate at 15,000 rpm.

Work is continuing on the experimental program for the determination of the total angular

momenta of the compound states corresponding to various slow neutron resonances with the use of polarized monochromatic neutrons and polarized nuclear targets. Recently resonances in Gd^{155}, Gd^{157}, Tb^{154}, Er^{167}, and Eu^{151} have been measured. An absolute method for such assignments has been devised and has been successfully applied to each of the above isotopes. This method makes use of a statistical weighting factor involving the Clebsch-Gordon coefficients associated with the relative orientation of the neutron and nuclear spins. The method is of considerable importance, since it removes the need to know the absolute signs of the hyperfine interaction constant, the nuclear magnetic moment, and even the direction of the applied magnetic field.

In addition to assigning spins to neutron resonances, the measurements yield the sign and magnitude of the nuclear magnetic hyperfine interaction. Of special interest are results obtained for europium and gadolinium, expressed in terms of local effective field at the nucleus: H_{eff} is negative for both EuS and Eu metal (magnitude not determined); and $H_{eff}=-(3.4\pm0.4)\times10^5$ Oe for Gd metal. Only a small polarization could be obtained in the Eu metal because it is antiferromagnetic; however, very substantial nuclear polarization was obtained in EuS, which is ferromagnetic. It was established that the sign of the nuclear hyperfine field is negative in EuS, since the observed magnitude of the neutron transmission effect at 0.364 eV is in excellent agreement with the calculated effect for an $I+\frac{1}{2}$ resonance and a negative hyperfine field and clearly inconsistent with an $I-\frac{1}{2}$ resonance and a positive field. Since the transmission effect in Eu metal is of the same sign, although much smaller, the sign of the field is also negative in the metal.

It was also observed that the nuclear relaxation time in EuS is strongly dependent on the applied magnetic field. Increasing the field from 10 to 17.5 kG increased the nuclear relaxation time from something less than 10 min to a value $\approx$15 times as great. This surprising result is now being investigated in greater detail.

As reported previously, neutron transmission measurements on polarized holmium nuclei in a holmium single-crystal sample had yielded a value for the coupling constant of $A/k=0.595\pm0.010$°K. This result was obtained by fitting the data to a spin ½ Brillouin function of the form

$$f_N=CB_I(A/2kT)\,,$$

where f_N is the nuclear polarization, B_I is the Brillouin function, and C is a constant. The constant C was found to be 0.92. For a single crystal and the applied external field of 10 kG, the constant C is expected to be unity. Efforts are being made to explain the discrepancy. Depolarization measurements on the holmium single crystal showed that total magnetization was indeed achieved. However, a detailed study of the neutron beam polarization showed that the polarization was lower than previously assumed. The lower beam polarization increased the value for the coupling constant to $A/k=0.605\pm0.005$, and the constant C increased to 0.975 for the best-fitting values. Any contribution to the nuclear polarization from the electric hyperfine structure has been neglected. There is evidence, however, that even a small electric hyperfine structure term will change the magnetic term appreciably.

Attempts have been made to polarize U^{235} nuclei by using the hyperfine coupling in the ferromagnetic intermetallic compound $U^{235}Fe_2$. The available specimen contained 1.10% U^{234} which produced an α-decay heating of $\approx$250 erg/sec. In an effort to cool such a sample to temperatures below 0.1°K, an exceptionally large paramagnetic salt pill, containing 1.7 kg iron-ammonium sulfate, was constructed to serve as the cold reservoir. Even this massive refrigerant failed to cool the UFe_2 sample appreciably below $\approx$0.7°K, and consequently the nuclear polarization was very small. Further investigation has indicated that UFe_2 has very poor thermal conductivity at low temperatures; this, together with the large α-particle heating, holds the sample at high equilibrium temperature. The nuclear polarization achieved could be observed but was too small to be useful in determining the spin dependence of the U^{235} neutron cross section. This work will be continued with U^{235} samples being prepared at ORNL from isotopes containing only 0.1% U^{234}.

The specific heats of U^{235} and U^{238} metals have been measured below 0.75°K. The results show a large T^{-2} contribution to the specific heat of U^{235} which is negligible in U^{238}. This indicates the presence of a large hyperfine interaction in U^{235}. The U^{235} specific heat can be represented by the expression

$$C_{235}=f(T)+\beta T^{-2}\,,$$

where the first term is the electronic and the second the hyperfine contribution. The data give $\beta=(10.9\pm0.7)$ mJ-deg/mole. Two possible choices for the

electronic term fit the data about equally well: $f(T)=12.1\ T$, or $f(T)=70\exp(-1/T)$ mJ/mole-deg. The latter is the approximate BCS expression for a superconductor with $\gamma=12.1$ mJ/mole-deg^2 and a critical temperature of 0.7°K. Since the data do not clearly distinguish between the two choices it was impossible to tell whether or not the sample was superconducting.

At present an unambiguous interpretation of the hyperfine specific heat of U^{235} cannot be made. Both nuclear magnetic and nuclear electric quadrupole interactions give rise to heat capacities proportional to T^{-2} in the high-temperature approximation. The assumption that the interaction is entirely electric leads to a value for its strength comparable to those obtained for U^{235} in various salts.

The U^{238} specific heat can be represented by the equation

$$C_{238}=\gamma T+\beta T^{-2},$$

where $\gamma=(12.1\pm0.3)$ mJ/mole-deg^2 and $\beta\approx0.15$ mJ-deg/mole. Although magnetic measurements have shown some samples of uranium to be superconducting, the U^{338} specific heat data cannot be fitted with an electronic term consistent with the BCS predictions for a superconductor.

The low-temperature specific heats of most of the rare earth metals have now been measured. Of all the measurements those on praseodymium are the most perplexing and are the only ones that are seriously sample-dependent below 1°K. Careful measurements have been made on Pr metal between 0.25° and 4°K. For the sample measured, a small peak at 3.4°K and a contribution to the specific heat which increases with decreasing temperature are found. This latter contribution, at temperatures above 0.5°K, can be described by $CT^2/R=6.4\times10^{-3}$. The temperature-dependence of this term, which is presumably a hyperfine interaction contribution, is not consistent with the recent hypothesis put forward by Bleaney that small ferromagnetic clusters exist in Pr metal. However, the existence of the peak at 3.4°K suggests that some sort of magnetic ordering may be setting in.

A very detailed study has been completed of the Doppler broadening of a neutron resonance over a wide temperature range. The purpose of these measurements was to test the practical validity of the theories in common use in recent years. Most neutron resonance analysis has used an ideal gas model to take account of Doppler broadening resulting from the thermal motion of the target nuclei. A more rigorous theory in occasional use was proposed by Lamb to take account of the lattice binding of the atoms in a solid target. To make practical use of the theory, an approximation which is known as the effective temperature model must be used. Despite the enormous effort devoted to neutron cross section measurements, there has been no careful experimental verification of the theory.

The 4.14-eV resonance in W^{182} was selected for investigation because of its narrow natural width and the desirable properties of metallic tungsten. The shape of the resonance was investigated in detail at several temperatures ranging from 4.2° to 825°K. At higher temperatures (above the Debye temperature) the Lamb effective temperature model was found to give an adequate description of the Doppler broadening for most practical applications. However, even at the highest temperatures small departures between observed shape and calculated shape were found. At low temperatures these departures were enhanced, and the effective temperature model did not give an adequate representation of Doppler broadening. A more elegant theory employing the actual phonon spectrum appears promising, and computations are now in progress to test its success.

In a cooperature program with Columbia University, a number of neutron crystal spectrometer measurements have been made on the dynamics of molecular motion in various families of inorganic and organic compounds and on other problems. These have included studies of the slow neutron scattering from CO_2 in the gas phase near the critical point, the scattering of neutrons due to rotational motion of methyl groups in synthetic and natural polymers as a function of sample temperature and neutron wavelength, magnetic inelastic scattering cross sections of manganese and iron compounds, first- and second-order phase transitions in hydrogenous compounds by total neutron cross section measurements, and the thermal diffuse neutron cross section of single quartz crystals at room and liquid nitrogen temperatures.

Equipment for a cryogenics laboratory, on which work was started last year, has been built and is being used in Mössbauer effect studies and liquid helium experiments. A He^3 cryostat enables experiments to be performed at temperatures down to 0.35°K, and a superconducting solenoid provides magnetic fields of up to 55 kOe.

The experimental possibility of observing the Mössbauer effect in suitably chosen liquids has been established. Experiments were performed using as a source Co^{57} in various host compounds which were dissolved in glycerol. By varying the glycerol temperature the viscosity could be varied over a wide range. Figure 23 shows the experimentally obtained linear variation of the emission line width with T/η (temperature divided by viscosity) of the source for $Co^{57}Cl$ in glycerol. The maximum line width studied was $\simeq$600 times the natural line width of the Fe^{57}. The line shape was approximately Lorentzian over the entire range of T/η studied. Similar results were obtained by using Co^{57} in porphyrin and hemoglobin with glycerol.

In all cases the line was centered near zero velocity, and no recoil effects were observed. These results provide evidence that the chemical entity in which the source nucleus is embedded diffuses classically during the time of emission of the γ ray. The results are in agreement with a theory of the Mössbauer effect in liquids proposed by Singwi and Sjolander, based upon Vineyard's calculation for neutron scattering from liquids.

ATOMIC AND MOLECULAR PHYSICS

The atomic beam magnetic resonance technique is being used to study hyperfine structures of various radioactive nuclei. The apparatus at Brookhaven is designed for work of extremely high precision. Nuclear magnetic moments can be measured with sufficient precision to permit the determination of nuclear hyperfine structure anomalies. Recently this work has centered on Lu^{176m} (3.7 hr). The magnetic dipole and electric quadrupole interaction constants have been determined with high precision for the atom in both the $^2D_{3/2}$ and $^2D_{5/2}$ electronic states.

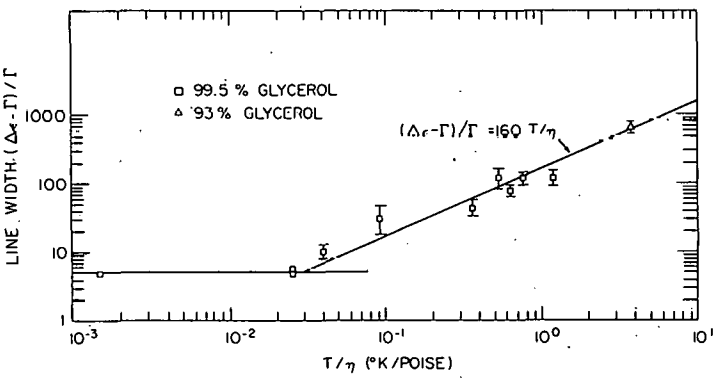


Figure 23. The diffusion broadening of the Mössbauer emission line of Fe^{57} in glycerol. The line width $(\Delta\varepsilon\text{-}\Gamma)\Gamma$ is shown plotted as a function of T/η (temperature divided by viscosity). The variation of the emission line width with T/η is seen to be linear over a range of 600 in the line width.

Higher-order effects are most clearly shown by comparing each interaction parameter in the two electronic states in Lu^{176m} with the same parameters in Lu^{175} (evaluated elsewhere). In particular, the ratio

$$\frac{\left[\frac{A(175)}{A(176m)}\right]_{5/2}}{\left[\frac{A(175)}{A(176m)}\right]_{3/2}} = \frac{[1+{}_{175}\Delta_{176m}]_{5/2}}{[1+{}_{175}\Delta_{176m}]_{3/2}} = 1.00328\,,$$

where $A(\ )$ represents the appropriate magnetic interaction constant and Δ the magnetic hyperfine anomaly, i.e., a small effect on the interaction energy arising from the penetration of the electrons into the nucleus. While the values of Δ cannot yet be measured separately, the fact that the difference of the two is as large as 0.3% signifies that the Δ's themselves may be quite appreciable.

A similar comparison of the electric quadrupole interactions, which are among the largest yet measured, yields the ratio

$$\frac{\left[\frac{B(175)}{B(176m)}\right]_{5/2}}{\left[\frac{B(175)}{B(176m)}\right]_{3/2}} = 1.000005\,.$$

The principal limitation at present on the precision of these ratios lies in the measurements of Lu^{175}.

The measured values of the interaction parameters for Lu^{176m} are, in cycles/sec,

$$\begin{aligned} {}^2D_{5/2}\text{:}\quad & A = 97{,}196{,}440 \pm 300\,, \\ & B = -635{,}193{,}140 \pm 700\,; \\ {}^2D_{3/2}\text{:}\quad & A = 73{,}172{,}850 \pm 300\,, \\ & B = -781{,}974{,}690 \pm 700\,. \end{aligned}$$

The new atomic beam apparatus, designed for high precision, greater sensitivity, and greater flexibility, has been completed.

SOLID STATE PHYSICS

Theory

Several theoretical advances have been made during the year. Studies on the dynamics of radiation damage in a bcc lattice (α-iron) have been

continued and extended to higher knock-on energies. The probability of divacancy production by a 100-eV knock-on was calculated by running >50 dynamic events in a large variety of initial directions to simulate isotropic distribution. At higher energies the effect of lattice anisotropy on the number of defects created was studied. A sequence of nonproductive replacements is caused by a knock-on in a penetrating direction, i.e., between the low-index crystal directions. The unusually deep penetration of heavy ions (superchanneling) has also been studied theoretically. Recent experiments have shown that a small fraction of a beam of heavy ions incident on a clean single-crystal surface penetrates deeply (several microns) into the crystal lattice. Such collisions provide a new means of studying the non-adiabaticity of slow atomic collisions involving large angular momenta. Unique conditions exist in channels because (a) impact parameters are independent of ion energy and are precisely known, and (b) the same atom makes a rapid succession of collisions with essentially constant impact parameter and kinetic energy. Calculations show that rare gas atoms can be multiply excited in their outer shells and lose electrons by auto-ionization in such collisions. A consequence of this process is enhanced penetration into the crystal lattice because the interaction potential governing their slowing-down will be greatly reduced after ionization. A model based on such collisional excitation and auto-ionization of channeled atoms explains the observed experimental results satisfactorily.

Calculations concerning the nature of point defects have been carried out with a lattice model simulating α-iron by using high-speed computer techniques. Iron interstitials, carbon interstitials, lattice vacancies, and various small clusters of these have been studied. The atomic configuration, the motion energy, and the motion volume have been determined for the different defects, and agreement with experiment, where available, is good. The iron interstitial migration energy was found to be 0.3 eV, which indicates that stage I radiation-damage annealing in α-iron proceeds by free interstitial migration. The carbon interstitial calculations tend to confirm and augment the model proposed to explain experimental results on the iron-carbon system obtained at BNL in the past few years. The iron-carbon interaction was represented by a cubic equation with the parameters chosen to yield the experimental value for the carbon migration energy and activation volume and the binding energy of a carbon atom to a vacancy. With this model the approximate experimental value of the energy of a carbon atom in solution in iron relative to Fe_3C was obtained. When the constants of the iron-carbon potential are scaled to nitrogen in iron and nitrogen in vanadium, the experimental activation volumes for diffusion of nitrogen, effectively zero in iron and 0.14 atomic volumes in vanadium, are obtained.

The distortion around a Cl^0 interstitial atom in a NaCl lattice and its relaxation energy have been obtained for various positions of the Cl^0 by a method involving the exact calculation of electrostatic, polarization, dipole-dipole, and repulsive energies. The relaxation of the order of 20 neighboring ions has been taken into account. The cube-centered and cube-diagonal positions are always found to be stable relative to the face-centered and face-diagonal positions. There are two energy minima of almost the same value along the body diagonal, one in the center of the cube and one straddling a Cl^- lattice position, separated by a potential barrier of $\approx$0.2 eV. The energy differences for the various configurations along the face diagonal are small, with the face center the position of lowest energy. The face-centered position is metastable with respect to the body-centered position by $\approx$0.03 eV. The energy difference between the body-centered and face-centered positions is 0.44 eV, which gives an activation energy along this line of motion of 0.47 eV.

A model has been proposed to explain fission fragment tracks in thin polycrystalline metal films. The model predicts that the fragment energy will be transferred to the electrons within a crystallite and thence to the lattice, which will cause evaporation provided that certain conditions are satisfied. One is that the energy per atom imparted to the lattice by the electrons exceeds the sublimation energy. Another is that the competing process of thermionic emission from the crystallite is quenched because the crystallite becomes charged. The latter condition implies that tracks will be observed in thin films of high resistivity, but not in those whose resistivity is about equal to the bulk value.

A number of theoretical problems in the field of magnetism have been completed. The theory of polarized neutron scattering was extended to include spin-orbit scattering of neutrons. This was motivated by a recent experiment in which interference between spin-orbit and nuclear scattering

was observed. The theory shows that in magnetic substances an additional effect due to interference between spin-orbit and magnetic scattering should be observable in a number of substances. The theory of spin-orbit coupling in atoms was developed for rare-earth and 4*d*-shell atoms and ions. Calculations of coupling constants from first principles showed good agreement with experiment. The spin-spin interaction in paramagnetic ions has been analyzed in detail. Calculations show that this interaction is weaker than previously believed. The theory of polarized neutron scattering by targets in which both electrons and nuclei are polarized has been completed and has been used in the analysis of a transmission experiment on holmium.

The shape of the soft x-ray emission spectrum of lithium has been calculated in the Hartree-Fock approximation taking into account the fact that an atom about to emit a K_β x ray is a point defect in the otherwise periodic potential. The perturbation from the 1*s* hole was treated in the lowest-order "strongly localized" approximation. Starting from Ham's calculated density of states function and gradually increasing the strength of the perturbation, one observes the formation of a resonance state (virtual bound state) and then a real bound state. For reasonable values of the perturbation parameter the results show a peak $\approx$1 eV below the Fermi energy, a feature which resembles the measurements of Crisp and Williams.

Crystal Imperfections

A major experimental research activity in solid state physics is the study of defects in crystals. While the main emphasis is on radiation effects in solids, other departures from perfect periodicity, e.g., order-disorder phenomena, are under active investigation.

The study of the effects of strain on color center formation and of radiation on mechanical properties in the alkali halides is being continued. Recent results indicate that straining a NaCl crystal modifies the well-known relation between the *M*-center and *F*-center concentrations. This relation is usually stated as follows: the *M*-center concentration is proportional to the square of the *F*-center concentration. In a strained crystal a constant additive term appears which increases with increasing strain. As an example of the effects of irradiation on mechanical properties, the changes in yield point of NaCl with increasing γ-ray dose have been investigated. The yield stress of unirradiated NaCl is $\approx$10 to 30 kg/cm^2. It increases monotonically with increasing γ-ray dose to $\approx$200 kg/cm^2 for irradiations of 6×10^7 R. There is a large change in slope at $\approx5\times10^6$ R which is apparently related to the defects present. This can be demonstrated by the behavior of *M*-centers. In crystals subjected to $<5\times10^6$ R, the *M*-center concentration, which is relatively low, decreases with time after the irradiation. In contrast, in crystals subjected to $>5\times10^6$ R the *M*-center concentration is about four times larger and increases after the irradiation is completed.

The γ-ray irradiation facility, which provides a means of making optical absorption measurements on samples while they are being irradiated, is being used to study the growth and annealing of *F*-centers in KCl. The study of the formation of *F*-centers as a function of dose rate at room temperature has been completed. The initial coloring was found to be proportional to total dose, i.e., independent of dose rate. In this region $\approx$100 eV must be deposited in the crystal by the γ-ray field to produce one *F*-center. The initial portion is followed by a region in which a steadily increasing dependence on dose rate prevails. The stability of the KCl *F*-center at room temperature was determined by coloring the crystals to saturation and then "turning off" the γ-ray field. The *F*-center concentration was then measured for periods of time extending from a few seconds to several days. There is an initial rapid decay, which is roughly the same in all crystals, followed by a very slowly decreasing component. From isothermal annealing measurements the kinetics were found to be bimolecular, which suggests that *F*-centers are destroyed by recombination of electrons trapped on vacancies with holes that have formed *V*-centers. This mechanism is supported by the observation that *V*-centers are formed by irradiation and disappear as *F*-centers disappear.

Electron spin resonance studies continue to yield detailed information about crystalline defects. In γ-ray irradiated α-Al_2O_3, for example, a single, asymmetric, paramagnetic-resonance absorption was produced with $g_\parallel=2.012\pm0.002$ and $g_\perp=2.008\pm0.002$, where $\parallel$ and $\perp$ are with respect to the *c*-axis. The line width is $\approx$50 G at 300° and 77°K. The absorption line has been analyzed as a superposition of three gaussian lines with the isotropic *g* values: $g_1=2.020\pm0.003$, $g_2=2.006\pm0.003$, and $g_3=2.006\pm0.003$. The component lines are tentatively attributed to two types of centers:

a trapped hole localized on an anion adjacent to a cation site which is deficient in positive charge, and an electron trapped at an anion vacancy. The cation site may be vacant or may contain a monovalent or divalent substitutional impurity.

A study is in progress of the effect of neutron irradiation of Al-Cu, a precipitating alloy. It was anticipated that the severe local damage associated with a displacement spike could serve as a nucleus for precipitation and that an acceleration of the precipitation process could be observed. (This effect has been observed and studied in Fe-C alloys at this Laboratory.) Preliminary experiments on an Al-Cu (1%) alloy have shown that neutron irradiation of $\approx 10^{16}$ nvt (fast) causes the resistivity decay curve at 110°C, associated with the late *GP* zone or early θ' phase, to be accelerated by a factor of 2 to 3.

Structure of Solids

Another major activity is the use of neutron and x-ray diffraction in structural and extrastructural studies of crystals. These have largely been confined to magnetism and vibrational characteristics. The work in these areas has been greatly strengthened by experiments involving the Mössbauer effect and by the establishment of a materials-preparation and crystal-growing laboratory.

Detailed measurements are being made on a natural single crystal of fayalite, Fe_2SiO_4, since powder data gave evidence of a noncollinear antiferromagnetic spin arrangement. The temperature dependence of the intensities of magnetic reflections shows that one component of the antiferromagnetic arrangement appears around 60°K, followed by the other at 30°to 40°K. Noncollinear magnetic structures have also been found over a wide composition range between ferromagnetic CrTe or MnSb and antiferromagnetic CrSb. Detailed measurements as a function of temperature have been made on selected compositions in order to determine the direction and magnitude of the various spin components.

A diffraction study of a single crystal of gadolinium has removed an ambiguity in the magnetic structure of this metal. A single crystal disk of gadolinium cut parallel to (00.1) has been studied in zero magnetic field. A careful search along the *c*-axis and perpendicular to it in the neighborhood of the (00.2) reflection has failed to reveal any satellites in the temperature range 77° to 290°K. Thus, unlike the rare earth elements from terbium to thulium, gadolinium is a normal ferromagnet. Above 248°K the moment is aligned along the *c*-axis. Below this temperature the moments make an angle with the *c*-axis which reaches a maximum of 75° at 195°K and approaches 30° at 4°K.

The unpaired electron density in the intermetallic compound $ZrZn_2$, reported to be ferromagnetic by Matthias and Bozorth, has been investigated. The magnetic scattering is very small ($\mu \approx 0.17\ \mu_B$ per molecule) but is readily observable with the highly sensitive polarized beam technique. The results show that the moment is almost entirely on the zirconium atoms and is more diffuse than would be expected for a 4*d* electron distribution, which suggests possible polarization of the 5*s* conduction band. Moreover, there is definite evidence for movement of electrons into the tetrahedral bonds joining zirconium atoms; the appreciable spin density along these bonds indicates that a localized model is inappropriate for explaining the ferromagnetism.

The distribution of magnetic moments in the Fe-Rh system has been investigated by neutron diffraction in the composition range between 35 and 50 atom % rhodium. These alloys have chemical order of the CsCl type; the body corner positions are occupied by FeI atoms and the body centers by rhodium and FeII. The magnetic moments in ferromagnetic alloys containing 35, 40, and 48% rhodium are $\mu_{FeI} = 3.1\ \mu_B$, $\mu_{FeII} = 2.5\ \mu_B$, and $\mu_{Rh} = 1.0\ \mu_B$ at 25°C. The moment of the FeI atom in the 50% rhodium alloy, which is antiferromagnetic at room temperature, increases to $3.3\ \mu_B$. A detailed study of the unpaired spin density distribution in the 48% rhodium alloy was made by the polarized beam technique. While the FeI atom has a nearly spherical density distribution, that of the rhodium atom shows a strong tendency toward e_g symmetry.

A number of crystals having the tetragonal scheelite structure have been examined with x-rays. These studies have yielded the heavy atom positions, but in most cases the oxygens could be located only from packing considerations, and in all cases the uncertainty in the oxygen position is quite large. With neutron diffraction data, direct refinement of all parameters is possible. Reliable oxygen positions have been obtained from such data.

Scattering of cold neutrons by light water and salt solutions is under investigation by means of the filter-cutoff technique. The method has been refined and energy resolutions of 2.5 and 1% have

been achieved. Broadening of the quasi-elastic peak has been observed as a function of scattering angle, but no evidence of low energy quantum transitions has been found. Measurements on a concentrated solution of NaCl do not show a decrease in the broadening, although it is known that the coefficient of self-diffusion of H_2O in this solution is $\approx$25% less than the pure water value. The data are being compared with various theories of cold neutron scattering by liquids.

Room-temperature Mössbauer spectra have been obtained for Fe^{57} in the following hcp metals: Cd, Co, Dy, Gd, Mg, Ru, (Se), (Te), Ti, Zn. The field gradients determined from the experiment show a c/a dependence in qualitative, but not quantitative, agreement with De Wette's calculation for a point ion model and a uniform conduction electron density. The measured isomer shifts are not fully explained by using conduction electron densities of the pure host metals but can be accounted for if the iron impurity is considered to be charged and screened by the conduction electrons of the host metal. The screening charge would also contribute to the field gradient at the Fe^{57} nucleus and might account for the quantitative differences in the observed field gradients and De Wette's results.

The BNL cold neutron facility has been used to obtain inelastic scattering cross section data from three first-row transition elements, titanium, vanadium, and nickel, and a random binary alloy, $Ti_{.67}$-$Zr_{.33}$. The vibrational frequency distributions have been computed from the data with use of an incoherent scattering approximation. These distributions exhibit peaks corresponding to major critical points. A comparison of distributions from different samples leads to the following conclusions: (1) the shape of the frequency distributions of the bcc metal (vanadium) and fcc metal (nickel) are remarkably similar, the relative positions of the critical points being the same for both; (2) the frequency distribution of the hcp metal (titanium), which has two atoms per primitive cell, shows structure corresponding to acoustical and "optical" modes of vibration; and (3) the Ti-Zr alloy has hcp structure, and its experimental frequency distribution is similar to that of titanium, except at low frequencies where alloying with the heavier mass zirconium atoms tends to smear out the peaks corresponding to acoustical modes. The frequency distributions above and below the critical temperature for the phase transition to bcc structure are different, the most striking feature being a shift of the high-frequency critical points to lower values in the high-temperature (bcc) phase.

The neutron inelastic scattering study of simple high polymers was continued. Vibrational spectra between 1000 and 30 cm^{-1}, derived from measurements of the inelastic scattering of cold neutrons, have been obtained for isotactic polypropylene at temperatures below and above the glass transition and the melting point. In addition to the skeletal optical modes, the neutron spectra for isotactic polypropylene indicate the existence of two acoustical modes, skeletal deformation and skeletal torsion, with high-frequency limits at 620 ± 50 cm^{-1} and 110 ± 10 cm^{-1}, respectively. As in polyethylene, these modes appear to be strongly influenced by the presence and phase of the disorder in the sample. Similar spectra for atactic polypropylene above and below the glass transition show a much less pronounced structure, although weak bands are observed which correlate well with the skeletal optical modes observed in the isotactic polymer.

High Energy Accelerators

The Accelerator Department is responsible for the operation, maintenance, and improvement of the Cosmotron and the Alternating Gradient Synchrotron (AGS). It also has the responsibility for advanced accelerator development programs and the design, fabrication, and operation of experimental community property such as beam separators and special magnets.

The activities in all these areas are summarized in the following sections.

ALTERNATING GRADIENT SYNCHROTRON

Operations

The demand for experimental time on the AGS continues to increase. Operation of the machine is on an around-the-clock schedule, 7 days/week. Intensities of 3 to 4×10^{11} protons/pulse are routinely accelerated. During the fiscal year, 6569 hr of operating time were available and were utilized as follows: high energy physics, 62%; accelerator studies, 6%; experimental setup, 3%; machine start-up, shutdown, and readjustment, 5%; accelerator failure, 17%; experimental equipment failure, 1%; downtime requested by experimenters, 1%; and routine maintenance, 5%.

In general the performance of the various machine components has been good. A continuous program of apparatus redesign is being followed in the attempt to improve over-all reliability.

Radiation damage to the transistors used in the AGS rf system has been a constant source of trou-

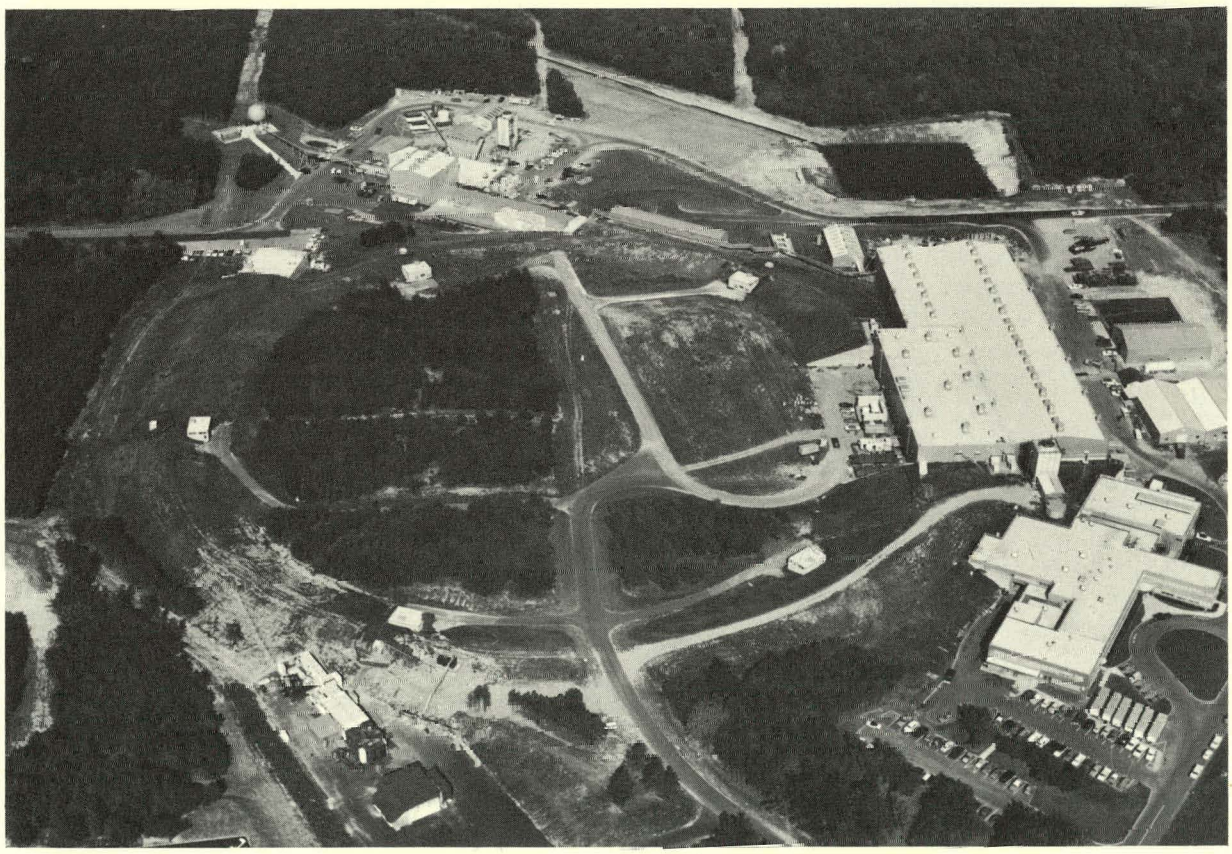


Figure 1. Aerial view of the Alternating Gradient Synchrotron.

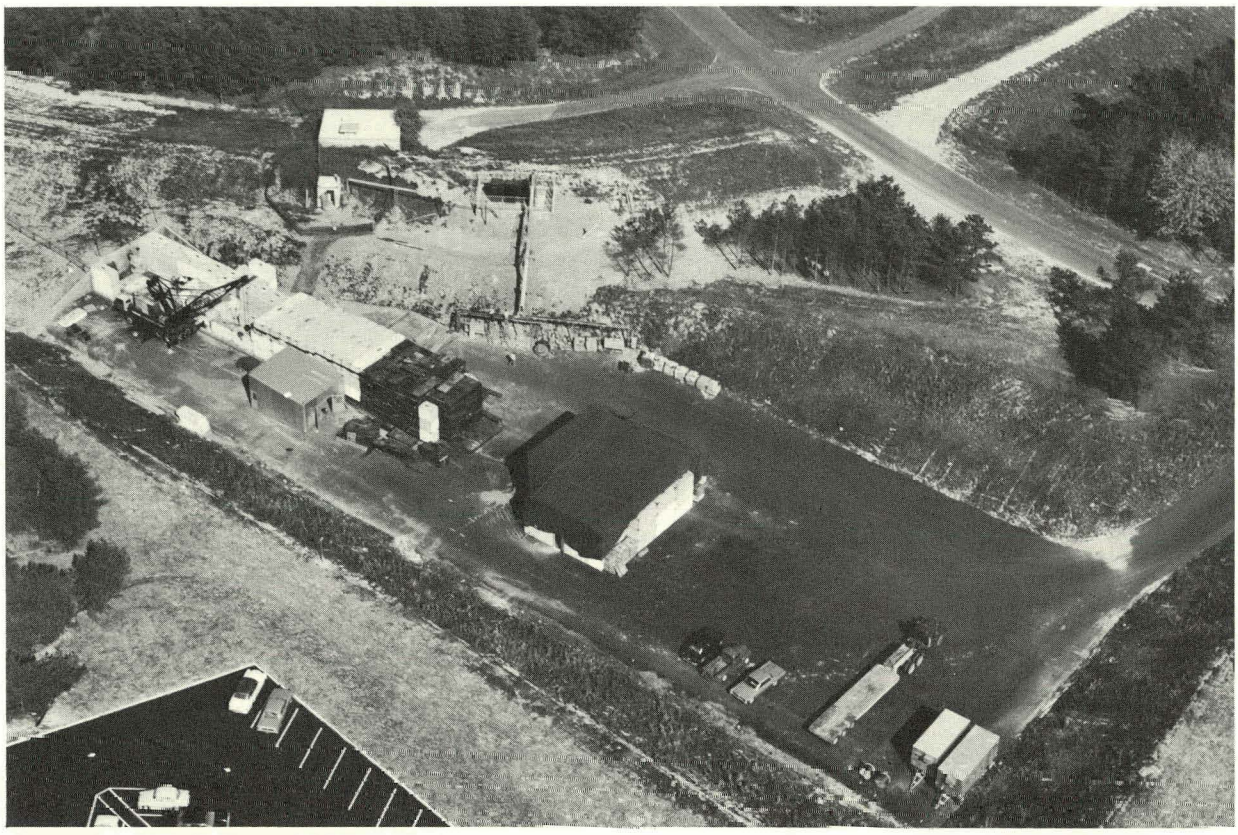


Figure 2. New Southwest Experimental Area.

ble. New circuits have been designed, and when fabrication is completed they will be mounted under a concrete radiation shield at each of the 12 power amplifier locations. A second source of difficulty has been vacuum leaks in the accelerating cavities. This problem is being solved in two steps. The first is the installation of vacuum flanges of an improved design as the failures occur. The second, a longer-term project, involves complete mechanical redesign of the assembly. The system changes instituted last year on the linear accelerator (linac) have resulted in a more stable injector for the AGS. The demand for higher intensities will be met with improvements in ion sources, an improved rf system, and replacement of the first few low energy drift tubes. The personnel safety and access control system for the synchrotron complex has been in use for most of the year. It has proved to be operationally effective and flexible to the changing machine requirements. The main magnet power supply has been pulsed 20.7 million times since its installation. The linac and AGS vacuum systems have performed well. Pump failures have been reduced by an effective maintenance program, and studies of advanced pump designs are continuing. Modeling and testing of equipment for rf-type separators are yielding sufficient data so that the design of the final system can proceed. The cylindrical and rectangular types of dc beam separators are in use on three beams at the AGS. One of these beams, which guides particles to the 80-in. bubble chamber, is composed of 6 rectangular separations connected to form 2 triplets.

A third experimental area of $\approx$45,000 sq ft was activated this year. The ring tunnel was breached and a 1-ft-diam pipe connecting the tunnel to the new Southwest Experimental Area was installed. The first experiment in this area was a second stage of the original neutrino experiment completed at the AGS. The area is completely outdoors, and preparations for the experiment involved the moving and erecting of 7600 tons of steel, 9100 tons of concrete, and 30 tons of lead, as well as the necessary magnets and detection apparatus. The final translation of an experimental

beam from a drawing to apparatus on the floor has become a matter of long-range planning. Availability of magnets, separators, vacuum apparatus, and raw and converted power is an important consideration in all scheduling for the machine. The beams erected and utilized for the recently completed program ranged from a simple test beam of relatively few elements to the complex beam to the 80-in. hydrogen bubble chamber, which utilizes 9000 kVA of power and consists of 28 beam transport magnets, 6 rectangular beam separators, 5200 tons of concrete shielding, and 450 ft of vacuum piping.

The main magnet of the synchrotron had its first coil failure on February 15, 1964. The shorted pancake was located and removed, and the machine was back in service in 16 hr. A water leak in one of the brazed coil joints was the initial cause of the failure. A destructive test of this joint showed that it probably had been improperly processed during fabrication.

On July 1, 1963, personnel associated with the AGS numbered 269. On July 1, 1964, the number was 297. This increase was necessary to accommodate the growing high energy physics program at the AGS.

Theory

Coherent Instabilities. When the beam in an accelerator becomes intense enough, the field it produces reacts on the beam itself and may produce instabilities limiting the number of particles that can be accepted.

One such instability, leading to growing transverse oscillations, has been observed at a number of accelerators, including the Cosmotron at Brookhaven. A theory to account for this effect, developed at Berkeley, has been modified and refined. The effect is known to arise from the finite resistance of the vacuum chamber walls. The theory postulates that the threshold for this effect depends on beam dimensions and on the spread in intrinsic betatron oscillation frequencies in the beam. Numerical calculations indicate that the present AGS intensity is close to the threshold, but so far the effect has not been observed at the AGS. At the Cosmotron, a simple servomechanism has been employed successfully to overcome this instability, and it appears plausible that similar measures can control any instability that may occur at the AGS.

Experimental Programs

In the past year, the program at the AGS has been expanded to include five experimental facilities. Furthermore, simultaneous operation of experiments in any four of these areas at a given time has been successful. A sixth facility is for radiochemistry work. Separated beam No. 1 from the F-10 target (described in the 1962 Annual Report) provides particles of medium momenta for the Brookhaven 20-in. bubble chamber. At the F-20 target, separated beam No. 2 (described in the 1963 Annual Report) provides particles with momenta up to $\approx$1 BeV/c for use with the Brookhaven 30-in. bubble chamber. The program of counter and spark-chamber experiments at the G-9 and G-10 targets areas has been continued with a modest expansion required by the increased complexity of such experiments. One new facility is separated beam No. 3, which uses a target placed in the I-10 straight section to provide high momentum particles (up to $\approx$9 BeV/c) for the new Brookhaven 80-in. bubble chamber. Another addition to the experimental facilities, located at the B-10 area, allows the internal beam to be extracted by a rapid ejection system and transported to an adjacent area for use by the experimenters.

More than 700,000 photographs have been taken of interactions in the deuterium-filled 20-in. bubble chamber resulting from particles obtained from separated beam No. 1. These photographs include 100,000 with antiprotons at 3.7 BeV/c for a Brookhaven group; 110,000 with K^+ mesons at 2.3 BeV/c for one group from the University of California at Berkeley and 20,000 with the beam tuned for deuterons at 4.0 BeV/c for another; 100,000 with K^- mesons at 2.3 BeV/c for the Indiana University group; 106,000 with 2.5-BeV/c π^+ mesons for the University of Illinois group; 60,000 with π^+ mesons at 3.7 BeV/c for the University of Michigan group; 30,000 π^+ mesons at 2.8 BeV/c for a joint Brookhaven–Johns Hopkins University group; 100,000 with 3.0-BeV/c π^+ mesons for the Columbia University group; and 75,000 with 1.7-BeV/c π^+ mesons for a joint group from Carnegie Institute of Technology and Brookhaven.

Following completion of this deuterium program the 20-in. chamber was filled with hydrogen. Since then, $>$300,000 pictures have been taken. Among these are 50,000 with K^+ mesons at 2.3 BeV/c for a group from the University of Cali-

fornia at Berkeley; 100,000 with 3.7-BeV/c π^+ mesons for a Brookhaven group, and 150,000 with 2.0-BeV/c π^- mesons for the University of Pennsylvania group. It is planned to obtain $\approx$300,000 additional photographs of interactions in hydrogen before the chamber is filled with deuterium again. A program totaling $\approx$400,000 photographs for several groups has been approved for studies using deuterium in the chamber.

Approximately 1.2 million pictures resulting from particles obtained from separated beam No. 2 have been taken in the 30-in. bubble chamber. Of these, 700,000 were for studies of stopped antiprotons and K^- mesons in hydrogen for the group from Columbia University. Exposures yielding $\approx$400,000 photographs to measure K^-p cross sections from 650 to 950 MeV/c have been completed. These have been divided between two groups, one from the University of Maryland and the other from Brookhaven. The Brookhaven group will study the momentum range from 650 to 800 MeV/c, while the University of Maryland group will study the higher momentum region. Several experiments for study of stopped K^- mesons and antiprotons in deuterium are in progress at the 30-in. chamber for groups from Brookhaven, Syracuse University, and the University of Illinois. More than 100,000 photographs have been obtained.

The approved program for the present separated beam No. 2 has $\approx$800,000 pictures remaining. It is planned to complete this program early in the fall of 1964. The beam will then be removed, and a new No. 2 beam, providing particles in the same momentum range but employing two stages of separation, will be installed. The design of this beam has been completed and the fabrication of special elements is in progress.

Separated beam No. 3 has been in operation since the fall of 1963. This beam is one of the most sophisticated to be installed at the AGS. It is designed to give a satisfactory intensity of $K^\pm$ mesons from $\approx$3.0 to 5.5 BeV/c and of antiprotons up to $\approx$8.5 BeV/c. It employs two stages of separation having 15 meters of electrostatic separator in each stage. Over 250,000 photographs have been taken in this beam. These consist of 60,000 with antiprotons at 5 and 7 BeV/c for a joint group from Yale University and Brookhaven; 75,000 with π^- mesons of momenta from 4 to 8 BeV/c for a Brookhaven group; 150,000 with 5-BeV/c K^- mesons for another Brookhaven group; and 10,000 with 8.5-BeV/c π^+ mesons for the University of Pennsylvania group.

At the G-10 target area 7 counter and spark-chamber experiments were completed last year. In July 1963 the μ-p elastic scattering experiment (described in the 1963 Annual Report) was completed. Concurrently with the above experiment a group from Princeton University used a neutral beam placed at 30° to the G-9 target on the inside of the ring. This group studied the regeneration of K_1^0 mesons in hydrogen and other materials.

Following the shutdown in August, an experiment to study large momentum transfer proton-proton scattering was installed for a joint Brookhaven–Cornell University group. This experiment used the hydrogen in a 1-mm-thick polyethylene disc placed at the G 10 target position to scatter the internal proton beam of the AGS. The scattered and recoil protons leaving the target were then momentum-analyzed by magnetic spectrometers placed at the correct angles to accept elastically scattered events. The positions of these magnets were changed as the momentum transfer was varied. Momentum transfers up to 24.4 (BeV/c)^2 were observed.

In November two beams were established on the outside of the ring in the G-10 area. One of these accepted particles emitted from the target at $\approx$5°, and the other, particles emerging at $\approx$12°. This configuration allowed two relatively elaborate experiments to run simultaneously. Four experiments using these beams were completed between December 1963 and April 1964. A Brookhaven group using the smaller-angle beam measured total cross sections of π^+, $K^\pm$, and $p^\pm$ on neutrons in deuterium for particle momenta between 6 and 20 BeV/c. The Johns Hopkins University group searched for leptonic decays of the ρ and ω resonances using the larger-angle beam tuned for 3-BeV/c π mesons. A group from MIT carried out an extensive measurement of the process $\pi^- + p \rightarrow \pi^0 + n$. Cross sections for the forward charge exchange process were obtained for momenta from 2 to 16 BeV/c. The larger-angle beam was used to obtain π mesons for momenta up to 6 BeV/c, while the smaller-angle beam provided particles for the higher momentum measurements.

In April two new beams were installed in the G-10 area. Their configuration is similar to that of their predecessors. In this case, the smaller angle beam was designed to transport higher momentum particles than the previous beam and will be

used by a Brookhaven group to study the differential elastic scattering of $\pi^{\pm}$, $K^{\pm}$, and $p^{\pm}$ by protons. This experiment employs counter hodoscope arrays connected on line to the Merlin computer. In the larger-angle beam, a Brookhaven group will carry out a high precision measurement of the total cross section for $\pi^{\pm}$ on protons in the momentum interval from 2.5 to 5.5 BeV/c.

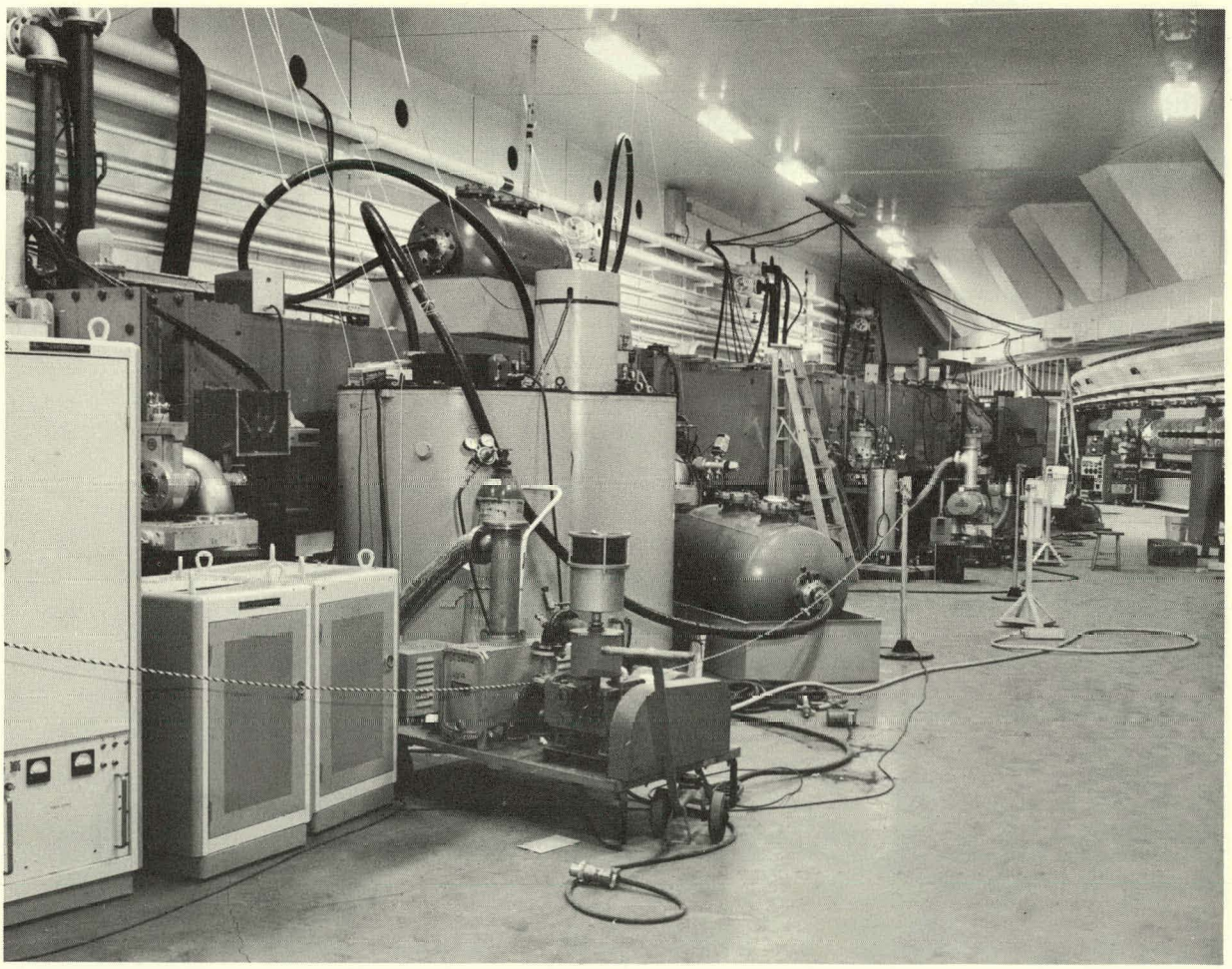
The rapid extracted proton beam at the B-10 area was operated successfully for a 3-week period. Measurements of proton fluxes by activating foils placed in the beam indicate that $\approx$86% of the circulating beam is extracted at 30 BeV/c. The present beam transport system focuses these particles on a 0.600-in.-diam target. This provides $\pi^{\pm}$ and $K^{\pm}$ mesons, which subsequently decay into neutrinos. The neutrino "beam" is then purified by a massive absorbing shield consisting of 7600 tons of steel and 9100 tons of concrete. The Columbia University group is using this facility for a spark-chamber experiment. To date, $\approx$1000 neutrino events have been observed.

The Chemistry Department has continued to use the AGS on an average of $\approx$2 hr/week for its studies with irradiated targets.

Linear Accelerator

The emphasis during the past year has been on three major areas of linac development. First, efforts to improve linac reliability have been continued. Second, development and design of various beam transport elements and linac drift tubes has been pursued. These items, when incorporated in the linac, will aid in the improvement of beam intensity. Third, further work has been done on the development of the duoplasmatron source and a short, internal high-gradient accelerator column.

Figure 3. Conjunction section beam No. 3 to the 80-in. bubble chamber.



To improve linac performance and reliability, work on the components for the 50-MeV pulsed momentum analyzer has continued. The laminated magnet is under construction, and the required electronic circuits are nearing completion. The whole system awaits final installation during the next major shutdown period. The over-all rf system has been further improved by the installation of an additional FTH 470 cavity. This allowed the preceding rf amplifier to be run more conservatively, which improved its sometimes erratic performance. Additional improvements on this system are under way. The low-level rf drive system has been duplicated and partly rebuilt. Easy switchover between the two systems is now possible.

In anticipation of high linac beam currents, satisfactory progress has been made on the over-all rf system modification. The hard tube modulator and power supply is being fabricated and will be installed shortly. A cavity for the 7835 tube (high-level system) is under study.

To improve beam stability with respect to energy spread, a significant amount of linac study time is being devoted to the study of problems connected with an rf field regulation system. Because of the closeness in frequency of standing wave modes other than the accelerating mode, it has not been a straightforward matter of constructing a servo loop; however, valuable information has been gained.

Significant improvement in over-all performance has been obtained with the installation of the new "lock-in" linac timing system. The linac beam pulse can now be accurately adjusted to the synchrotron acceptance time without affecting interdependent linac rf, chopper, and ion sources pulses. The greatest benefit is that rf beam loading in the cavity can now be made constant in amplitude and shape, which permits more consistent compensation. Preinjector performance has been improved, mainly by the installation of a pulsed 120-kV focusing supply. With this supply and the pulsed extraction supply, it is now possible to run higher voltages on the beam focusing elements. As a result, preinjector output currents with the PIG source are now $\approx$80 to 100 mA. However, linac intensities have not been $>$25 mA, partly because beam losses occur with the present Cockcroft-Walton-linac beam transport system (1-in. diam).

Development and design of the 3-in. beam transport elements is nearly complete. In addition, the new drift tubes with associated quadrupoles for the low energy section only of the linac are practically finished.

Progress has been made in the development of high-intensity duoplasmatron ion sources. It is now possible to obtain $\approx$500 mA of total beam from an expanded plasma from a modified duoplasmatron source. Sophisticated emittance measurements are under way. To handle these high intensities adequately, a short, high-gradient column has been designed and a prototype section will be tested shortly. The internal beam optics and electrode shapes are being studied.

Development and Engineering Programs

Power. During the year the AGS primary power distribution system operated very satisfactorily. There were no service interruptions except those scheduled for expansion of the basic system. A few voltage dips did occur; these were due to both internal and external malfunctions.

Approximately 50 million kWh of energy were consumed in the AGS complex. The maximum demand on the feeders varied from 40% to 85% of feeder rating, with an over-all average of 66%. Many of the experimental branch circuits were loaded at times to full capacity. However, the various peaks did not occur at the same time.

A new substation of 2300 kVA capacity was installed to service the apparatus for the Southwest Experimental Area (neutrino experiment). In addition, the engineering design has been completed for 10,000 kVA of electrical power. When the equipment (two portable substations) is installed, the secondary power will be distributed to the East Experimental Building.

A study of various types of water-cooled cable was undertaken. A satisfactory system has been adopted for use in areas of heavy concentrations of dc power for experimental magnets.

The main magnet power supply for the AGS was pulsed $\approx$7.5 million times during the year. On September 12, 1963, the slip rings of the main motor flashed over, with considerable damage to the rings, rigging, brushes, etc. All defective equipment was replaced or repaired, and the system was operational in $<$48 hr. Two problems that still cause some difficulty are the erratic behavior of motor control equipment and the poor cooling of the alternator on very hot days. Solutions to both problems are being implemented.

Mechanical - General. A large-aperture bending magnet with a peak field of 15 kG has been

designed for use in the experimental program. The magnet is 3 ft long with a 2-ft-high by 10-ft-wide aperture and is designed to translate 6 ft and rotate 40°. The movement will be achieved hydraulically by using flat hydrostatic and semihydrostatic bearings. The total weight of all components is ≈400,000 lb. The core is on hand and has been assembled, and work is continuing on the fabrication of the coils and hydraulic and control equipment.

The design of a special "C" magnet for use on the low energy separated beam has been completed. This magnet can be mounted close to the synchrotron orbit, which permits the beam to be deflected away from the machine at a production angle of 12° toward the inside of the ring. The result is a considerable increase in the flux of K^- mesons in the separated beam. The design field is 15 kG.

The fast ejection system for the primary proton beam was installed and put into operation during the past year. The major components are the ferrite kicker to apply the initial deflection, a rammed septum, and a rammed ejector magnet. For beam transport to an external target, vacuum chamber sections totaling ≈260 ft, 3 pickup electrodes, 6 pitching magnets to raise the beam 10 ft to the level of the Southwest Experimental Area, and 7 focusing magnets were installed. After some difficulty with the system, an extracted proton beam was successfully delivered to the neutrino experiment during a run of ≈3 weeks.

A plasma lens for use in conjunction with the neutrino experiment has been designed and fabricated. This device is used to focus the mesons produced after interaction of the external beam with a target to increase the neutrino flux and the number of events in the spark chamber. The device consists of 2 electrodes separated by a dielectric tube ≈2 m long, which form a vacuum chamber. Argon or a similar inert gas is bled into the vacuum chamber at 100 to 500 μ to serve as a conductor between the electrodes. Power modules supply a pulsed voltage of 16 to 18 kV for 20 μsec during every machine pulse; this results in a plasma arc between the 2 electrodes. The ground return path is supplied by a stainless steel tube surrounding the electrode and dielectric tube assembly, and the coaxial unit thus formed cancels out stray fields. Total weight of the assembled unit is ≈700 lb. The lens has been used with some success with the beam. Details of the electronic system for the lens are given below under the heading "Electronics."

Motor-driven flip targets have continued to perform reliably with no failures. Some of the mechanisms have exceeded 4×10^6 cycles. One remote cycling airlock has been installed in the AGS ring and has performed satisfactorily.

As beam intensities in the AGS increase, induced activities in some machine locations exceed tolerances for even the shortest practical operations. To overcome this problem the Department has undertaken the development of special-purpose handling devices. These include a programmed target blade changer, a complete airlock which can be remotely replaced, and, in a very early stage of planning, a mechanism for the remote changing of a complete targeting straight section. Investigations into the possibilities of general-purpose remote handling devices are also progressing.

Vacuum. During fiscal 1964 the vacuum system on the linac has been most effective and reliable. The pressure has remained in the low 10^{-7} torr region throughout the year.

The ion source vacuum pumps have given considerable difficulty because of an increase in the amount of hydrogen gas being put through the source. A pair of high-speed mercury diffusion pumps has been purchased to replace the Evapor-Ion pumps on the system.

The ring vacuum system has been strained to the limit by an increase in the number of experimental boxes located in such areas as *L*-10, *A*-10 and *B*-10. These are all potentially high leak-rate, high outgassing-rate areas, and supplementary pumping systems have been placed at these spots. Other high outgassing boxes, e.g., those in the *F*-20, *G*-10, and *I*-10 areas, will be equipped with large sputter-ion pumps purchased for this purpose.

One superperiod ("D") has been operating for 3 months with sublimation pumps. These have required no maintenance or attention during this period, and the pressure has been averaging 2 to 3×10^{-7} torr. It is expected that all ring vacuum pumps will be equipped with sublimation devices as rapidly as installation time can be scheduled.

Controls. The personnel safety and security system for the magnet enclosure, linac tunnel, and associated areas has been completed and is operational. Various minor modifications and refinements have been made to improve the system's effectiveness. In addition, the system has been extended to include the external beam tunnel in the Southwest Experimental Area, which presents a

particularly high radiation hazard during external beam operation. Additional circuits with appropriate door switch interlocks, remote operating circuits, and special key-operated switches have been incorporated in the plasma lens circuits to protect personnel from high voltage hazards. Various control and coaxial cables have been installed from the Southwest Experimental Area and the external beam equipment to both the main control and experimental control rooms to permit integrated operation of these activities. The vacuum system for the external beam pipe has been appropriately interlocked and instrumented for safe and proper operation.

Since the circuits of all vacuum system components are "fail-safe" and in addition can be started only locally, power failures of even short duration often result in several hours of machine downtime while the system is being restored. Therefore an auxiliary power supply driven by a gasoline engine to provide continuous electrical power has been specified and will be used to supply power to certain key circuits of the vacuum system. In addition, time-delay relays will be incorporated in other circuits to permit power-failure override.

The public address system serving the entire AGS complex has been reviewed and certain additions and modifications have been designed. In particular, the arrangement of preamplifiers, power amplifiers, and associated circuits centrally located in the main control room has been revised to include simplified graphic panels, built-in circuits for component and feeder checking, and various patch cord facilities. These features will make possible direct and quick methods for finding system faults and substituting components. Provision is included for convenient and orderly expansion of the public address system. These facilities are now in the process of fabrication.

DC Beam Separators. Electrostatic beam separators continue to be used in 3 beams: the beam to the 30-in. bubble chamber (1 rectangular separator); the beam to the 20-in. bubble chamber (2 cylindrical separators); and the beam to the 80-in. bubble chamber, in which 6 rectangular beam separators joined together to form 2 triplets are currently being used to provide $\approx$100 ft of electric field length.

Stable operation has been achieved with the rectangular separators by using an electric field voltage of 450 to 500 kV on a 4-in. electrode gap. Voltages of 350 to 400 kV continue to be used on a 2-in. gap with the cylindrical separators. Instrumentation and control systems have been improved and modified so that electric and magnetic fields are automatically restored after separator spark-offs. In addition, tank pressures in the region of 10^{-4} to 10^{-3} torr can now be controlled more precisely.

The three short separators are being assembled. One of them has been completed and is undergoing tests to determine the electrical and magnetic characteristics of this type of separator.

RF Beam Separators. Testing of the various components and systems for an rf beam separator is continuing.

The dimensions of the deflecting iris-loaded waveguide were finalized. A 40-iris prototype with waveguide couplers was delivered and subjected to cold tests. High-power and deflection tests remain to be done. The 118-iris waveguides (3 m long) for a 3-deflector system have been ordered. A modulator (65 MW with 5-μsec flat-top) for klystron tests was delivered. It uses a thyratron KU274 switch tube and has proved to be very reliable. Two more modulators of identical design are on order. A 20-MW klystron TV2011B2 has been tested and seems satisfactory for the separator. The similar klystron RCA A1230G is being evaluated. A limiting factor of an rf separator is the attainable phase stability, and considerable effort was required to solve this problem. A precision phasemeter for dc and pulsed signals was developed, and a phase servo system is being tested. The varactor multiplier chain is now operational; it exhibits, however, a detrimental phase modulation. An alternative scheme using a single multiplication through a step recovery diode is under development.

Studies have been completed of suitable beam transport systems incorporating 1 rf separator stage (2 deflectors, 40 m apart) for exposures in the 80-in. hydrogen bubble chamber. It is proposed to use a second fast external beam emerging at straight section *I*-10 (North Experimental Area) with an external target as a source of secondary particles. This beam system will coexist with the present dc separator facility (beam No. 3) everywhere except near the bubble chamber. Two classes of experiments can then be performed interchangeably without displacement of heavy equipment: (1) rf separated particle beams ($\bar{p}$, $\pi^{\pm}$, and $K^{\pm}$) in certain momentum regions between

10 and 20 BeV/c, and (2) unseparated beams of π^- mesons and protons of up to 30 BeV/c. Furthermore, it will be possible to transport the external beam at full machine energy to a location outside the conjunction tunnel to the North Experimental Area.

Electronics. The control of the main magnet power supply has been converted to a solid-state system. This system regulates the firing of the ignitions to minimize ripple and firing faults and also controls the power supply during flat-top operation. The converted system has been in use for several months, and no difficulties of any kind have been encountered. The flat-top slope is held to a desired position so that proper beam spills on targets can be maintained.

A design has been completed for the main magnet ripple filter. All the power tubes and auxiliary components are on hand, and initial assembly is starting. A supply has been placed on order which will enable the high-power shunt tube to have enough anode-cathode voltage during flat-top operation when the main magnet voltage drops to <1000 V.

The "bump" magnets for the multiturn injection trials have been assembled, and the power supplies for pulsing them have been built. The new vacuum system hardware for mounting these magnets in the ring at the L-7 and A-13 locations is being fabricated.

The radiation damage to the transistors in the rf power amplifier saturating supplies has been an increasingly serious problem. In two locations (H-20 and K-10) transistor degradation occurred after several weeks of operation. At H-20 the transistor bank was removed in October 1962 and placed under concrete shielding. There have been no subsequent transistor failures. When a cleanup target was installed at K-1, the downstream spill was damaging the supply at K-10. The entire saturating supply was repackaged and placed under concrete and it, too, has had no further failures. All components have been ordered to construct 15 (including 3 spares) new saturating supplies packaged to roll under a concrete shield. These will be similar to the unit at K-20. They will be adapted for quick disconnect and it will be possible to change an entire supply in a few minutes.

In the main control room the program for changing over to solid-state construction is continuing. The variable time-delay units and peaking-strip chassis have been so modified. The entire timing system has now been converted.

The plasma lens utilizes the magnet field associated with current flow in a gas plasma to focus pion beams. The plasma is contained within a fused silica tube $\approx$2 m long and 40 cm in diameter. A 100-kJ storage bank was constructed to generate the plasma. This comprised 33 modules each containing a capacitor and discharge ignitrons. The system runs in the 16 to 18-kV range and is capable of delivering a pulsed current of 10^6 A. The modules were life-tested to >1 million pulses at 33 kA/ignitron. A separate 30-kJ bank provides an axial magnetic field to control the plasma pinch rate. The first runs were made at the start of 1964 with argon or argon-nitrogen gas mixtures. Unexpectedly high resistive losses associated with pinch effect limited the peak current in the lens to $\approx 0.5 \times 10^6$ A. The probe measurements of field show that the current distribution can be made reasonably constant within the plasma. The lens was used operationally for a short period in April 1964. The development of this lens has been a cooperative venture between Brookhaven and Columbia University (Physics Department).

The components of the system to extract the AGS beam were installed in the summer and fall of 1963, the first external beam being achieved at the end of October. During the next few months the system was calibrated for optimum performance and unreliable components were weeded out.

The thyratrons in the fast-kicker power supply have now been pulsed 1 million times with no sign of deterioration. This life was the design objective. The only major failure during this time was a capacitor short in one of the 4-Ω pulse-forming networks. Many parts of the high-voltage assembly of the fast kicker were fastened together with nylon screws, which have started to fail mechanically because of radiation damage. Servicing the fast kicker was complicated by the high radiation levels present; this situation was alleviated by placing a cleanup target upstream to minimize beam spill on the ferrite magnets.

The septum power supply has proved to be very reliable. On two occasions ground currents resulting from shorts in the septum magnet have caused the current regulating circuit to become unstable and further damage the septum magnet. Several independent protective circuits have now been installed to automatically shut down the power supply if ground currents occur.

The storage capacitor bank and high current switching ignitrons of the ejector magnet power supply have performed well without any failure to date. The charging supply for the capacitor bank determines the azimuthal stability of the external beam by ensuring that the pulse-to-pulse jitter in deflected angle is low. The power supply has excellent stability, but the reliability of the regulating circuits has been poor, a component failure occurring every 100 hr or so. A new supply is being designed for the ejector to be installed at the *I*-10 location.

Survey. The survey group furnished marks for the advanced construction of the Southwest Experimental Area as well as positions for its experimental equipment. A triangulation was extended above the ring from stations formerly used for controlling the North Experimental Area in order to complete as much of the construction as practicable before shutting down the machine to install the exterior beam pipe for the Southwest Experimental Area in the tunnel wall.

Some difficulty was encountered with radiation exposure when realigning magnets near the target box some 36 times at intervals of 6 to 100 hr between runs of the *p-p* elastic scattering experiment. Careful monitoring and rotation of personnel was necessary to avoid overexposure.

The machine with its supporting structures is operationally stable within 0.020 in. except when large changes are made in shielding loads or construction is in progress near it. A change of 1000 tons in its immediate vicinity is likely to cause a settlement or rebound of $\approx$0.060 in.

Mechanical Services. All cooling systems of the AGS have performed well and without interruption of accelerator operation during this period. Treatment of the primary cooling well water with complex phosphates continues on a carefully controlled basis. This treatment and the use of copper-lined heat exchanger tubes have decreased the frequency of mechanically cleaning the exchanger to twice a year.

Two closed-system, 1-MW water coolers operating with an ethylene-glycol solution have performed satisfactorily in the Southwest Experimental Area. A 12-MW cooling tower has provided additional capacity for the East Experimental Area. In addition, demineralized-water, closed-system cooling equipment ranging in capacity from 10 to 200 kW has been designed for use with those systems having special water-cooling requirements.

A new 256-ft^3/min 600-psig helium compressor has been installed and placed in operation. This new facility doubles the high-pressure helium available at the synchrotron for experimental use.

Advanced Accelerator Development

The program of the Advanced Accelerator Development Division a year ago included studies of super energy accelerators and of storage rings for use with the AGS. The latter study was not initiated by Brookhaven but was undertaken at the recommendation of the Ramsey panel (the President's Scientific Advisory Committee – General Advisory Committee joint panel on high energy accelerators). During 1963 it became evident that the storage ring project did not have the unanimous support of the AGS users, and a summer study was organized during June and July of 1963 to explore the probable usefulness of storage rings at Brookhaven and to compare their desirability with that of other possible projects. The proceedings of that study have been published as Informal Report BNL 7534, *1963 Summer Study on Storage Rings, Accelerators and Experimentation at Super High Energies*. The summer study and many subsequent discussions indicated that there is much more interest at Brookhaven and among outside users of Brookhaven's facilities in improvement of the AGS than in the addition of storage rings. Specifically, it appears desirable to increase the intensity of the AGS beam by as large a factor as can be achieved. Consequently the storage ring study has been discontinued and an AGS conversion program initiated. In addition, the design study for a 600 to 1000-BeV accelerator is being continued, since it appears to have enthusiastic support in all quarters.

This year the AGS is expected to reach the space charge limit for the present 50-MeV injection, and a further increase in intensity will be possible only if the injection energy is increased. The first step in the conversion program will be the replacement of the present injector by a new 500-MeV linac. This will increase the AGS intensity by a factor of $\approx$10. Another factor of 2 will be gained by additions to the AGS magnet power supply to double the present cycling rate of the machine. These two changes will raise the average AGS intensity to $\approx 2\times10^{13}$ protons/sec.

Major changes in the AGS itself will be necessary as a consequence of the increased intensity. Shielding must be added in many places, and structural

changes must be made to support or enclose this shielding. Residual radioactivity will reach such levels that many operations now done manually must be reorganized for remote handling. Components that require appreciable maintenance will be removed from the AGS tunnel to a new equipment gallery above the AGS ring. Changes and additions will be made in experimental beams and areas to allow full use of the increased intensity and to give additional flexibility in the use of the machine. It is expected that simultaneous experimental operations can be expanded materially when the new intensity is reached.

A proposal for the AGS conversion program has been prepared and will be submitted to the Atomic Energy Commission during the summer of 1964. Approval will be requested for construction to start during fiscal 1966.

Many of the design studies in support of the AGS conversion are equally necessary for the 600 to 1000-BeV project. Shielding problems, remote handling techniques, and methods for controlling residual activity will apply in quite similar fashion to the super energy accelerator. In addition the super energy study now includes work on magnet design to establish the optimum magnetic field for the 600 to 1000-BeV machine. In the light of recent analysis by the Midwestern Universities Research Association, magnet modeling has been postponed and magnet studies are in progress using computers. This now appears to be a more efficient approach. Attention also is being given to developments on superconducting magnets; it appears possible that the use of such magnets in accelerators will soon become practical. Probably the major activity in the super energy study is in the high energy physics group, whose members are giving much attention to the probable experimental program in the new energy range. Conclusions about this program will have a profound influence on the design of the machine itself, on the arrangement of components to make desired experimental beams available, and on the location of the machine and its experimental areas for maximum usefulness.

COSMOTRON

During fiscal 1964 the high energy research program at the Cosmotron was varied. Total cross sections for proton-neutron and neutron-neutron collisions were measured in the neutral external beam from the Cosmotron. A search was made for a neutral boson that might be detected from an analysis of the velocity spectrum of a slow He^3 nucleus resulting from a proton-deuterium collision.

Work in pion physics was extended by a thorough investigation of neutral pion production from negative π mesons colliding with protons for incoming pion momenta in the region around 1 BeV/c. An experiment in which a deuteron and pions are formed in proton-proton collisions is in progress in connection with a study of pion production multiplicities. Measurement of the 2-body process in which 1 pion is formed is complete.

Research in K-meson physics was active with counter–spark-chamber experiments for measuring the lifetime of the K_2^0 and the electronic decay rate of the K^+ meson. The K_1^0 regeneration in heavy elements was determined, and a hydrogen bubble chamber experiment has begun to measure K_1^0 regeneration from protons. Two experiments are in progress to investigate the decay products from stopped K^+ mesons. In this work, aimed at determining the nature of the weak interaction, information will be collected on the momentum distributions of the μ^+ and e^+. The angular distribution of the decay electron from the muon will determine the polarization of the decay muon. The decay rate of the K_{μ_3} will be further studied.

Three experiments concerned hyperons. The magnetic moment of the Λ hyperon has been measured; work has been completed to determine the rate of the leptonic decay mode of the Λ; and a counter–spark-chamber experiment to detect a short-lived, bound state of the Σ^- and the neutron has satisfactorily passed the particle detection phase.

Of the total beam time available for research in high energy physics, 70 to 75% was scheduled for experiments conducted wholly or in part by institutions other than BNL. Although the time required to perform experiments in some cases exceeded the original estimates by factors of 2 or 3, all attempts were successful insofar as the acquisition of data was concerned.

During the first half of fiscal 1964, the Cosmotron reliably circulated beams of 4 to 5×10^{11} protons/pulse; however, during the latter half of the year beam intensity was between 2 to 3×10^{11} protons/pulse. The reduction in beam intensity was partly due to performance of the acceleration tube in the Van de Graaff injector. Jitter of the emergent beam position prevented the injection

system from being tuned to a sharp maximum. Steps are being taken to realize the best accelerator tube that recent developments in tube technology will permit.

The loss of circulating beam intensity did not impair the progress of the experimental program. The experiments scheduled during this period largely made use of the counter–spark-chamber combination. In all cases these experiments required attenuation of the circulating beam if it was in excess of 3×10^{11}, usually because the response times of the anticoincidence counter circuits were insufficiently short to reduce background in the spark chambers to a level that would permit high scanning efficiency.

Operational reliability of the Cosmotron for the year was the best in its history. There were no shutdowns lasting more than two weeks. Beam time for experiments in high energy physics rose from 55% in 1963 to over 70% in 1964, and accelerator failure fell from 13% to slightly more than 8%. The change from corona-point voltage gradient control to fixed resistors in the Van de Graaff injector eliminated a large source of ozone production and increased the charging belt life by a factor of 10, which reduced the downtime required for opening and closing the Van de Graaff tank for belt changes. The conversion of the magnet water-cooling system from evaporative cooling to heat exchange with ground water permits a more rapid repetition rate during times of high humidity and temperature. The removal of the proton beam bunching during flat-top spill enables the experimenter to make full use of the 250-msec spill duration, as compared to the 60 to 100-msec duty time available last year. Although these last two items are not reflected in the time analyses shown in Figures 4 and 5, they nevertheless materially increase the efficient use of experimental time. During the year the average machine pulses per month increased from 400;000 to 700,000.

Preventive measures against prolonged machine shutdowns have been taken in the case of vacuum chamber leaks. Special jigs and fixtures have been built and an overhead crane has been installed adjacent to the magnet ring. Vacuum chamber quadrants can now be removed without removal of the massive radiation shielding and the consequent risk of machine misalignments resulting from disturbances to the floor loading.

Many improvements not directly related to increased usage of beam time have been made. Ionization chambers have been rebuilt with responses linear within 10% for the normal ranges of external beam intensities. Digitized scalers displaying the beam intensity have been located in the control room and at convenient points in the experimental area. Four radius-positioning target rams and a remotely controlled jump target are ready for installation in the vacuum chamber.

Accelerator studies were particularly fruitful with respect to the elucidation and solution of a circulating beam instability which, if uncontrolled, would limit the development of high-intensity proton accelerators. It is well known from electromagnetic theory that a beam of charged particles will create electrical images in the metallic struc-

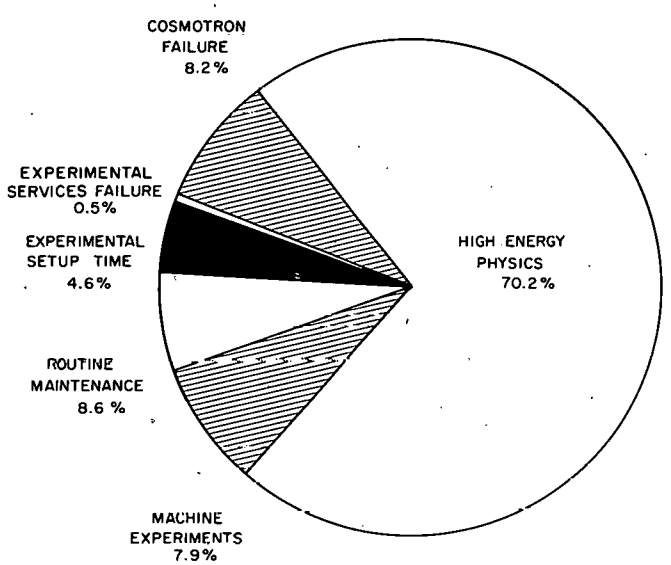


Figure 4. Cosmotron utilization during fiscal 1964.

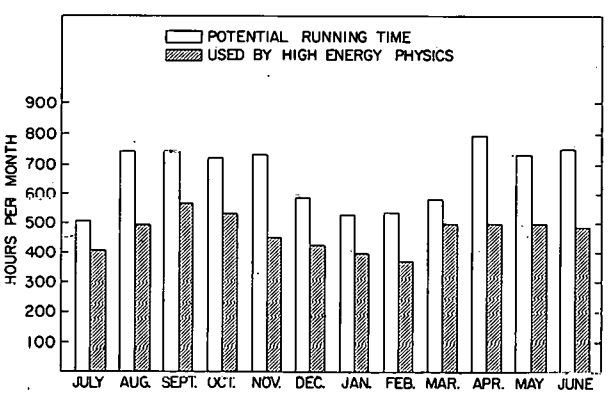


Figure 5. Use of the Cosmotron for experiments in high energy physics during fiscal 1964.

tures surrounding the beam. Theoretical consideration of this phenomenon showed that for materials of finite electrical resistivity a coherent out-of-phase energy coupling between the proton bunch and its image exists. The sign of one of these couplings is such as to cause the beam, when a critical intensity is reached, to break into a coherent vertical oscillation which will grow until the entire beam is destroyed by the vacuum chamber wall.

Pickup electrodes, tuned to the proper frequency, were installed in the Cosmotron. They sensed the buildup of this effect as induced voltage. These pickup signals were amplified, shifted in phase, and applied to a second set of electrodes which canceled the growth of the instability. Reversing the phase of the correcting electrodes lowered the proton intensity threshold for appearance of the oscillations. Theory predicted several discrete frequencies for these vertical oscillations. However, study of the equipment installed in the Cosmotron showed that one of these frequencies controlled all the others; hence correction of the problem at this frequency solved the problem at all frequencies. In addition to the Cosmotron, beam instabilities arising from the same cause had been observed on two other accelerators.

The hydrogen target group now includes 19 persons engaged in the design, construction, testing, operation, and development of cryogenic targets for the entire high energy program at the Laboratory. A target controlling the density of liquid hydrogen to 1 part in 10,000 was supplied to an experimental group.

This year all liquid hydrogen (nearly a million liters) was bought from outside vendors. The hydrogen liquefier at the Laboratory is in stand-by condition. Storage capacity for liquid hydrogen is being increased from 3000 to 14,000 gal. This group, the sole supplier for gaseous deuterium, electrolyzed $>132{,}000$ ft^3 during fiscal 1964 for experimental use at the Laboratory and for off-site institutions such as CERN, Argonne, Carnegie Tech, Princeton, and the Lawrence Radiation Laboratory.

The Cosmotron complex activated a new wing chiefly for housing the machine shop and drafting facilities. The area formerly occupied by the machine shop has been converted into engineering laboratories.

Instrumentation

RESEARCH AND DEVELOPMENT

This year substantial advances were made in computer applications and automatic data handling systems. Spark position detectors with digital output were developed and tested. There was continuing progress in the development of circuits and of semiconductor radiation detectors.

Last year a data processing system for high energy physics experiments was described. This system has been improved and expanded. Several hundred fast logic circuits (gates) have been built to obtain digital output signals from scintillation detectors. Three buffer storage systems were assembled. These are arranged to receive digital data from experiments at a very high rate during an accelerator pulse and to reproduce the data at a slower rate between pulses for computer analysis and for recording on magnetic tape. The storage section is a commercial computer memory unit with a capacity of 4096 words of 48 bits each. Control circuits were added to perform the desired loading and unloading operations. A set of coaxial lines was laid between the AGS Building and the Merlin computer for transfer of data at a high rate. The new equipment can handle $\approx$100 times as much data as the original and can be used in 2 experiments simultaneously.

Single-gap wire spark chambers have been studied for use with the system described above to determine the trajectories of high energy particles. After passage of a particle a high voltage is applied to one electrode, which causes a spark discharge to one of the many wires in the other electrode. Each of the wires passes through a small ferrite core. Current from the spark reliably sets the associated core. When the particle track passes midway between adjacent wires, both cores are set, so that the spatial resolution is somewhat finer than the wire spacing (1 mm). With appropriate gas filling and high-voltage pulse characteristics, the efficiency is nearly 100%, spurious sparking is rare, and recovery time ($\approx$200 μsec) is very much shorter than that of conventional spark chambers.

Several of these spark position planes will be used in an experiment, each plane having several hundred parallel wires and cores. A system has been designed to scan the cores in groups of 32 and search for cores that have been set by sparks. When one is located, a 16-bit binary address is generated and transmitted to the buffer memory for future analysis. A system with three planes, scanning circuits, buffer memory, and magnetic tape output has been tested at the Cosmotron (Figure 1).

Another computer system has been developed for neutron time-of-flight analysis in cooperation with R. Chrien of the Physics Department. The system consists of time-measuring circuits, a commercial digital computer (SDS 910), and a cathode ray tube (CRT) (Figure 2). Two experiments and nonrelated computations may be run simultane-

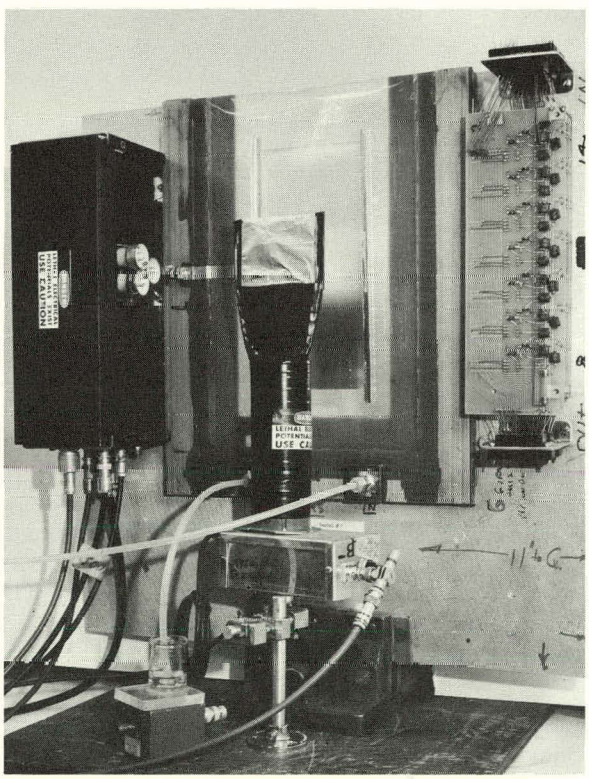


Figure 1. Wire spark chamber. One electrode consists of 225 parallel wires threaded through cores; the other is thin aluminum foil. High-voltage pulse circuits are at left, and cores and readout circuits are at right.

ously. Separate electronic clocks are provided for the two experiments. When a neutron is detected, the appropriate clock is read and the computer signaled to accept data. The computer interrupts its program, stores the data, and then returns to the program. One computer program generates on demand a CRT display of the data accumulated in either of the experiments. Experimental runs are controlled and results typed or punched out upon command of the console typewriter. Computer input-output lines go to a patch board so that there is a wide choice of channel assignments, time ranges, display modes, etc. The system may be expanded to handle both pulse-amplitude and time-of-flight information.

Work has begun on a computer system to control and record the data from seven neutron crystal spectrometers.

In the field of semiconductor radiation detectors, factors affecting the generation of noise have been investigated. The bulk material is of very high purity, and the main source of noise is believed to be at the surface, where a single layer of foreign atoms may have a profound effect. An apparatus was built to measure the surface potential and conductivity by means of probes, and a computer program was written to determine the internal electric field distribution which matches the measured surface potentials. Measurements on lithium-drifted silicon detectors showed that after cleaning and exposure to room air the surface was n-type, like the lithium-rich region, instead of intrinsic. Ideally, the potential should drop smoothly from one electrode to the other. Instead, there is a virtual short circuit at the surface so that most of the potential drop occurs in a very short

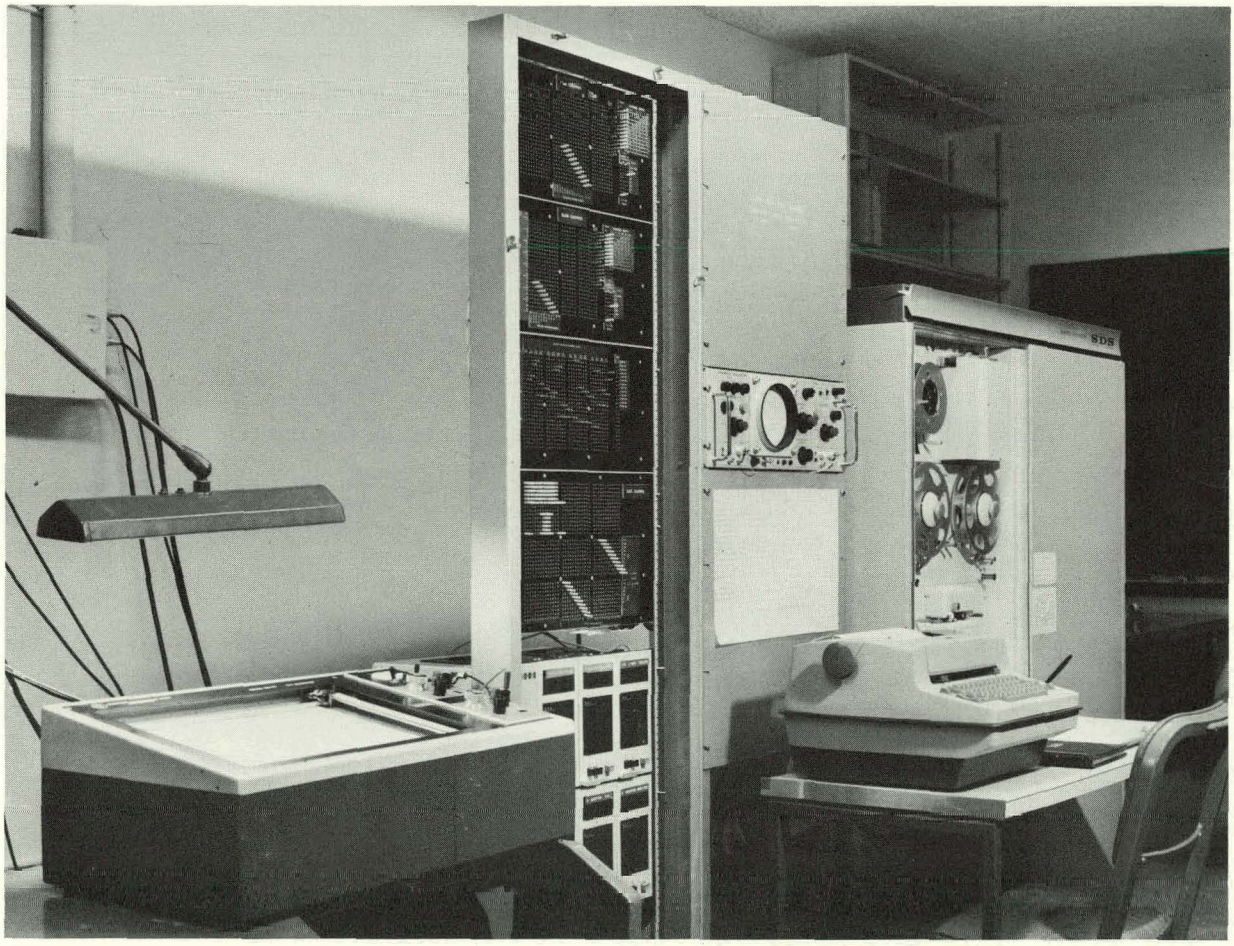


Figure 2. The Physics Department's neutron time-of-flight analyzer, showing plotter, patch board and CRT, and computer.

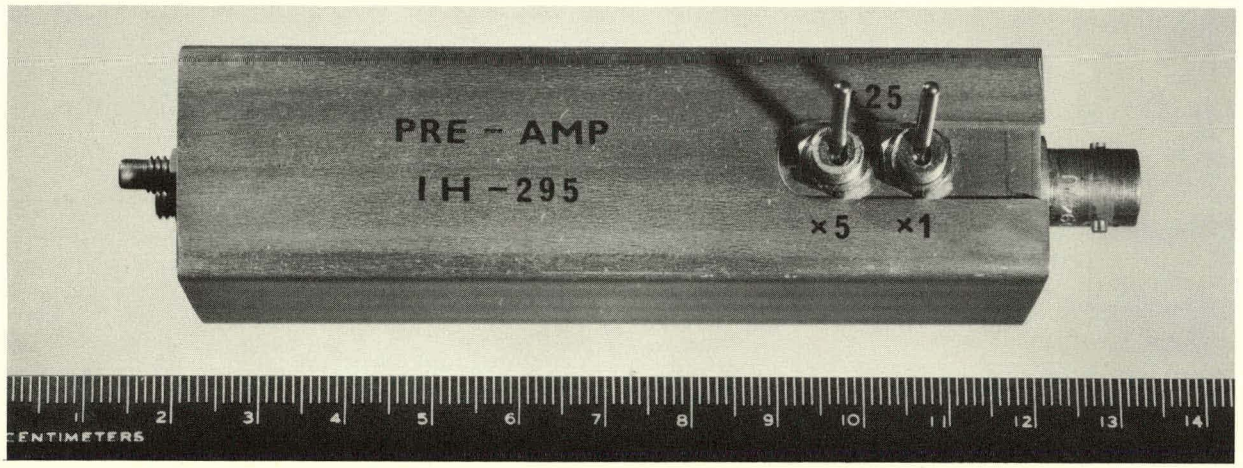


Figure 3. Low-noise preamplifier using field-effect transistor.

distance at the p-type terminal. This surprising result emphasizes the need for more care in the preparation and protection of the detector surface.

Further work with field-effect transistors has clarified their advantages and limitations. They have been used in a low-noise preamplifier for use with semiconductor detectors. The preamplifier is small, can be used inside a vacuum system, and has a wide range of sensitivities (Figure 3). An analogue multiplier circuit was developed which can form a product in 0.02 μsec.

Circuits have been designed to sense differences in shape of detector pulses, regardless of amplitude. They may be used, for example, to separate scintillation pulses from photomultiplier tube noise or to tell when two pulses are almost superimposed.

The 1962 Annual Report described several methods for automatically stabilizing the gain of a pulse-height analyzer system. A more versatile system was designed this year. Reference pulses may be obtained from a precision pulse generator or from certain standard radiation sources. The reference pulses should fall into a specified channel or channels in the analyzer. Errors are sensed digitally, and the gain or zero settings of the system are adjusted automatically to correct the error. The system is flexible and more straightforward than previous models.

A vibrating capacitor electrometer has been built with a digital output. The analogue-to-digital conversion is done inside the feedback loop. The circuit will be used with an ionization chamber to record background radiation and can be operated on the ac power lines or on batteries. The digital output, recorded on paper tape, makes it possible to cover a wide range of intensities. Sensitivity and stability were not impaired by combining the analogue and digital circuits.

A number of special-purpose circuits were built during the year. One of these simulates radiation damage in glass. The heavy glass windows in "hot" cells are expensive. Under intense gamma radiation, displacement of charge within the glass gives rise to electric fields which may become high enough to shatter the window. An electronic analogue model has been built. When it is in use an ionization detector is placed by the window. The circuit integrates the radiation and causes charge to leak off in the same way as it does within the glass window. A meter indicates the field within the glass, and an alarm is tripped before a dangerous situation can occur.

LABORATORY SERVICES

About 25% of the Division's man-hours are now devoted to repair and service activities. As the amount and complexity of research equipment increases, so does the need for skilled technicians. Three small digital computers were obtained during the year, and a technician was engaged to maintain them. An instrument pool has been instituted in conjunction with the Supply and Materiel Division, which collects unused instruments and repairs and reissues them. This has already resulted in a considerable saving of money. A few examples will illustrate the variety and scope of the services performed: construction of a num-

ber of low-background proportional counters, neutron detectors, and x-ray detectors; repair of 81 counting circuits, 30 multichannel analyzers, 116 oscilloscopes, 115 meters, 50 spectrometers, and hundreds of other items; construction of 600 assorted small circuits, 2400 cables, and 300 printed circuit boards; conversion of the police radios for narrow band operation and repair of all on-site receivers and transmitters; and calibration and repair of 630 health physics radiation monitors on a quarterly schedule.

METEOROLOGY

The Meteorology Group has expanded slightly during the past year. There are now four members of the scientific staff as compared to two during fiscal 1963. One addition has also been made at the professional level.

Instrumentation

In many respects, the most important work accomplished during the past year has been the completion of the wind instruments and auxiliary recording equipment necessary for many other phases of the research work. Thirty-five fast-response anemometers have been completed. Built according to the design and techniques worked out in earlier years, they are particularly suitable for low-level turbulence and wind profile work. The development of recording devices for use with these anemometers has also been important. The devices are of various types, depending on the data required. One, for example, is a highly reliable printing-counter assembly, capable of recording the inputs from several anemometers simultaneously and permitting the determination of mean wind profiles to an accuracy of $\approx 0.5\%$.

The investment casting techniques used in fabricating the components of the anemometer have resulted in instruments suitable for hurricane recordings. One currently in use at the top of the 420-ft tower (Figure 4) is identical in appearance to other Brookhaven equipment, but it can withstand 200-mph winds because its exterior parts are of stainless steel.

The investigative phase of altering the paper-tape recording system, which has been in use at Brookhaven to record meteorological data for the past five years, has been completed. The new anemometers demand an increase in the recording speed capability, and the older system will be converted from paper to magnetic tape as soon as final details can be worked out.

Particulate Studies

The diffusion-deposition field work, involving Cu^{64} spheres and uranine dye, has been confined largely to an initial study of the behavior of the tracers in forested areas. This change was made partly because of the basic interest of the Meteorology Group in extending the studies into the forested areas and partly because of difficulties in the operation of the main deposition field. The vacuum system serving 150 sampling positions in the deposition field was initially equipped with plastic pipe, which was thought to be more adaptable to climatic changes as well as less expensive than a metallic installation. Unfortunately, the

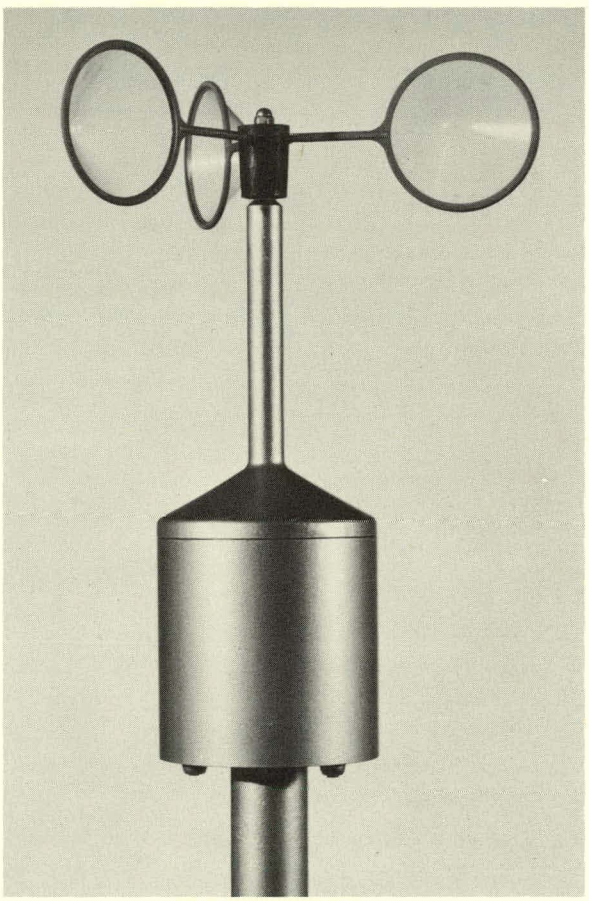


Figure 4. Three-cup anemometer, typical of the 35 now in use at the Laboratory. These instruments are formed from investment castings and are both strong and uniform. The instrument shown has stainless steel components and will withstand winds >175 mph.

plastic has not lived up to expectations, and complete conversion of the field to a metallic-pipe vacuum system has just been effected.

In addition, careful study of the initial airborne concentration data showed the behavior of the filter samplers to be somewhat disconcerting. The investigators had expected that the efficiency of the Millipore samplers would be a strong function of the horizontal wind speed when large (5 to 10-μ) particles were involved, and wind tunnel tests had been undertaken to establish factors to correct for this. Data observed in the field, however, showed that the collection efficiency for copper spheres appeared to be sensitive to atmospheric stability as well as the horizontal wind speed. This in turn suggested that the basic problem might be sensitivity to slight changes in the angle of attack of the wind, and accordingly a refined series of experiments, patterned after some earlier work at the University of Michigan, was conducted. These tests showed that changes in the angle of attack of the wind of as little as 10° could produce substantial variation in the collection efficiency for 5 to 10-μ copper particles. Revisions in the field installation have been made to include impactor-type samplers for determination of the airborne concentration of the copper particles, since there is no possibility of deriving a reliable correction factor for the filters. Fortunately, these difficulties with the samplers invalidate only a small portion of the data collected earlier and do not substantially reduce their value.

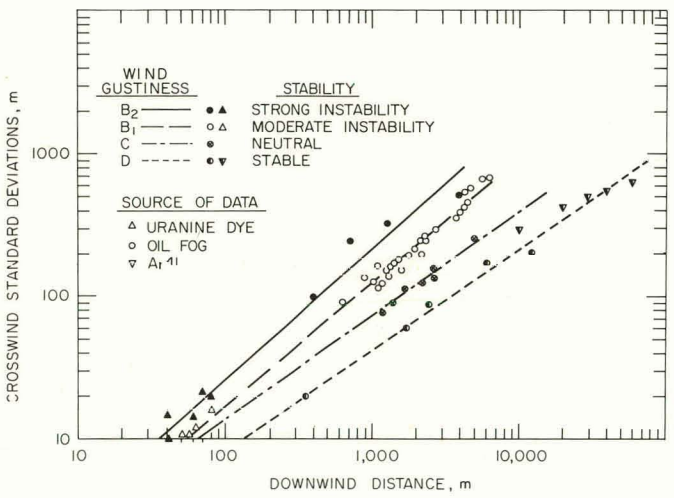


Figure 5. Standard deviations of tracer plumes derived from all the various diffusion studies conducted at the Laboratory. These separate distinctly according to the four types of wind gustiness used routinely for the classification of atmospheric turbulence in this area.

The study of the penetration of particulates into forested areas has been conducted with ragweed pollen and Cu^{64} spheres with intriguing results. The tests, which are still too limited to be fully conclusive, suggest that particles emitted close to the edge of the forested area diffuse into the woods in a manner almost identical to that found over open terrain.

The work with ragweed, timothy, and corn pollen has progressed very satisfactorily. Analysis of data obtained in 1962, as well as the first portion of the 1963 material, has for the first time revealed the relationship between deposition of the pollen particles on flat-plate collectors and estimates of the deposition derived from the change in the mass flux of the pollen through successive sampling sectors downwind. The agreement, which is generally within a factor of 2, is both surprising and encouraging in view of the inherent difficulties in obtaining accurate estimates of the mass of tracer material passing through a given y-z plane.

Diffusion Parameters

Partly in response to the need for the best possible specification of diffusion parameters to be included in the forthcoming revision of the AEC's 1955 publication entitled *Meteorology and Atomic Energy*, a thorough review has been conducted of all atmospheric diffusion data obtained at Brookhaven. This has included concentration data from oil fog and Ar^{41} released from elevated sources, as well as low-level estimates based on the uranine studies of recent years. The data fall into easily recognized classes of diffusion conditions, as shown in Figure 5, and are in very good agreement with similar estimates based on the results obtained at similar installations throughout the U.S. and Great Britian.

Wind and Turbulence

Until the final portion of the present fiscal year, much of the study of wind and turbulence has consisted of planning new experimentation and conducting a detailed literature search on specific problems of interest to the Group. Perhaps the most significant finding, from both the literature survey and the initial records from the accurate anemometer-counter assemblies, has been the indication of the need for a painstaking review of wind profile theory. In studies of this problem,

the differences among the more important theoretical formulations are difficult to distinguish unless the experimental data are both adequate in number and extremely accurate. Now that the Group is in a position to obtain such data routinely, it is hoped that some of these questions, such as the validity of the logarithmic relation between wind speed and height under neutral meteorological conditons, can be resolved.

Cloud Rise Studies

Field experiments on the rise of hot clouds have been awaiting the development and testing of heat sources that could be depended upon to be constant over short periods of time. When tests indicated that very uniform rates of heat release could be obtained over periods as short as 10 sec, full-scale experiments were resumed, in June.

Chemistry

The researches in the Chemistry Department are carried out by members of the staff, postdoctoral appointees, and visitors from other institutions. The fields include experimental and theoretical studies in nuclear reactions and spectroscopy, geo- and cosmochemistry, activation analysis, chemical effects of radiation (both primary radiations and recoil particles), molecular and crystal structure, chemistry of isotopes, inorganic solution chemistry, and ion-molecule reactions.

HIGH ENERGY NUCLEAR REACTIONS

The principal aims of the high energy reaction studies are (1) to obtain information on the systematics of the very complex patterns of reactions observed, i.e., knowledge of how the cross section for formation of any particular product depends on bombarding particle, on bombarding energy, and on mass and atomic number of target nucleus; (2) to gain an understanding of the reactions in terms of mechanisms and models. Additional goals of at least some of the reaction studies are, on the one hand, to correlate the behavior of complex nuclei under high energy bombardment with interactions between elementary particles and, on the other hand, to obtain information on the structure of atomic nuclei.

From knowledge of reaction cross sections alone, it is usually not possible to deduce reaction mechanisms. Greater insight into the details of reactions can be obtained if, in addition, there is information about the energy and momentum transferred to the reaction products. Such information comes from experiments on the angular and energy distributions of reaction products recoiling out of extremely thin targets. Experiments of this type are therefore receiving increasing emphasis. Additional details about reactions are obtained from observations of the various charged particles (recoil nuclei, fragments, α particles, protons, mesons) in nuclear emulsions and in bubble chambers.

The detailed interpretation of high energy reactions in terms of mechanisms usually involves comparison of experimental results with calculations based on certain models, and these calculations are so complex as to require extensive use of high speed computers. In particular, Monte Carlo methods have been found very useful in this work.

Studies of the interaction of high energy protons with various target elements (e.g., Al, Cu, Ag, Pb, U) have continued at the Cosmotron and the AGS, with emphasis on more specific problems. The production of nuclei with mass numbers in the range of 7 to $\simeq$25 is under study by a variety of techniques for the purpose of investigating the mechanism of fragmentation in high energy nuclear reactions. Cross sections have been measured for the production of delayed-neutron emitters (Li^9, C^{16}, N^{17}) from various targets in this mass range. Conventional radiochemical procedures have been used to obtain cross sections for Na^{22} and Be^7 production and ranges for the latter. High sensitivity mass spectrometry has been used to measure production cross sections for the stable Ne isotopes from a variety of targets, and a fast gas transport system has been employed to obtain cross sections for Ne^{24} production. Studies of delayed-proton emitting isotopes have also been started. The aim of all these studies is to obtain information concerning the nuclear charge distribution in the fragmentation process.

To illustrate some of the conclusions emerging from these studies, Figure 1 shows the recently determined cross sections for the production of the delayed-neutron emitter N^{17} by 3-BeV protons, together with older data for production of F^{18}. The descending (left-hand) branch of the curves is ascribed to formation of the products as spallation residues, the ascending (right-hand) branch to the fragmentation process. The latter mechanism is seen to be greatly enhanced for the neutron-excess product N^{17} (neutron/proton ratio 1.4) relative to F^{18}, which lies near the β-stability line (neutron/proton ratio 1.0), whereas the spallation mechanism shows the opposite trend.

Several different approaches are being used to obtain additional information on the phenomenology and mechanisms of fission processes induced by multi-BeV protons. Comparisons between the cross sections for formation of a wide variety of products from lead and from uranium

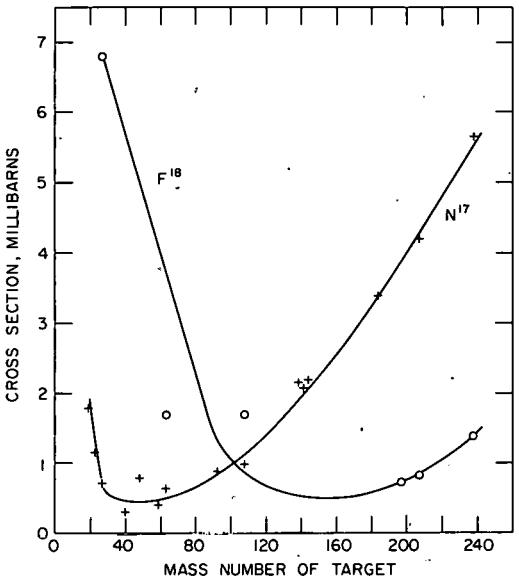


Figure 1. Formation cross sections of N^{17} and F^{18} in 3-BeV proton bombardments of various targets.

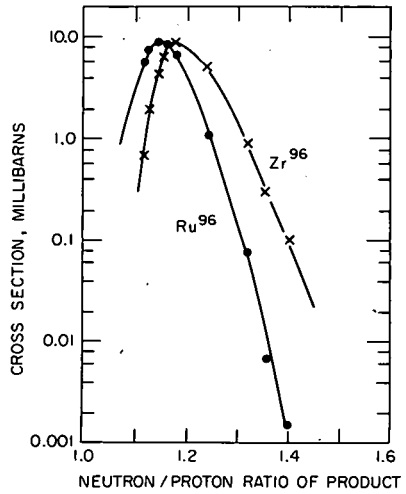


Figure 2. Cross sections for products in the mass region $66<A<74$ formed by 1.8-BeV proton bombardment of Zr^{96} (neutron to proton ratio, $N/Z=1.40$) and Ru^{96} ($N/Z=1.18$). The data for Mo^{96} targets ($N/Z=1.29$) are intermediate.

targets have been under way and await detailed analysis. Angular distributions and differential ranges of several uranium fission products have been measured. These indicate substantial differences between the neutron-excess and neutron-deficient products (see Figure 2), in qualitative agreement with what might be expected if these products arise, as has been previously hypothesized on the basis of charge distribution data (see Figure 3), from low energy and high energy processes respectively. Further analysis will presumably give information on the time scales of the breakup processes. Differential range curves for several products from silver irradiated by 2.9-BeV protons have been obtained in an attempt to distinguish between spallation and fission mechanisms. These data have been compared with predictions of Monte Carlo cascade plus evaporation calculations and with emulsion data. The comparison indicates that Na^{24} is formed in a two-body breakup (fission), but that products heavier than or equal to $A=42$ are probably spallation residues.

Previous studies of the $Cu^{65}(p, p\pi^+)Ni^{65}$ reaction have been extended to include measurement of differential range curves and the angular distribution. The results are being compared with predictions from a calculation based on a one-pion exchange model. Whereas such a model fits the thick target integral range data reasonably well, agreement with the differential data is less satisfactory. However, this discrepancy appears to be due

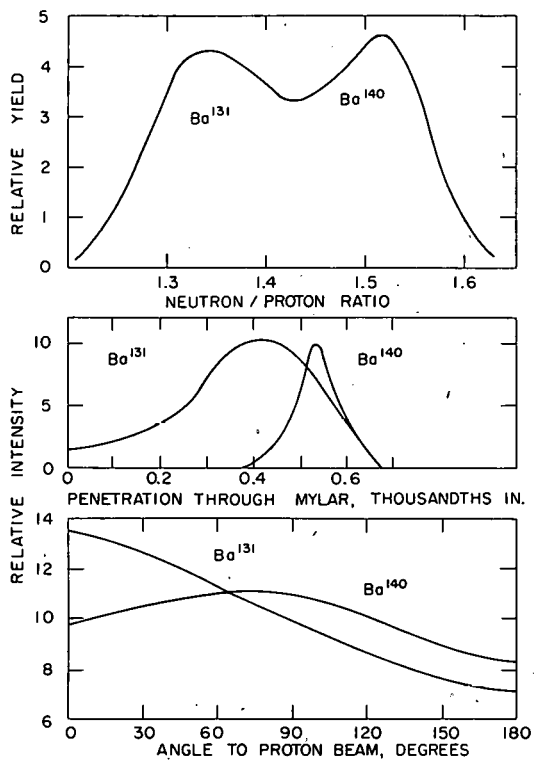


Figure 3. Data indicating two modes of high energy fission of uranium. The upper figure shows a plot of yield vs neutron/proton ratio of the product. The two peaks correspond to the two modes. The center figure shows the energy spectrum (as measured by penetration through Mylar) of one representative product from each peak. In the lower figure, characteristic differences in the angular distributions of products typical of the two modes may be seen.

to the oversimplified nuclear model assumed rather than to failure of the one-pion exchange model.

Further absolute determinations of cross sections for the monitor reaction $C^{12}(p,pn)C^{11}$ have been made at proton energies of 50 MeV and 1 BeV to fill gaps in existing data. A summary of the cross section data for this reaction is given in Figure 4.

Monte Carlo Cascade Calculations

Continued use is being made of the IBM 7094 computer for Monte Carlo calculations of internuclear cascade processes. The object of these calculations is to obtain quantitative predictions of the results of the interaction between high energy bombarding particles and complex nuclei. These calculations represent a considerable extension and refinement of earlier published work. They have already been carried out for incident nucleon energies below 400 MeV (where pion production can be neglected) and have proved the importance of using the proper nuclear density distributions and of including reflection and refraction effects.

Pending extension of these new calculations to higher energies, considerable use has been made of the results of the old cascade calculations in conjunction with Monte Carlo calculations of the evaporation phase of the reaction. Results of these calculations are being compared with various experimental data to test whether a particular reaction can be accounted for by the two-step (cascade plus evaporation) mechanism of high energy nuclear reactions. In one such study, with targets of Ru^{96}, Mo^{96}, and Zr^{96}, the neutron/proton ratio of the target material was found to have marked effects on the isobaric yield distribution of spallation products some 25 mass numbers below the target mass (see Figure 2). These results are in fair agreement with the Monte Carlo calculations. In another investigation, the experimentally observed cross sections for much simpler reactions, of the type p,pxn, were found to be significantly higher than the calculated ones when x is 2 or 3, although the discrepancy is not as large as in the previously investigated p,pn reactions ($x=1$). The refinements in the nuclear model incorporated in the new cascade calculations appear to improve the agreement with the experimental data.

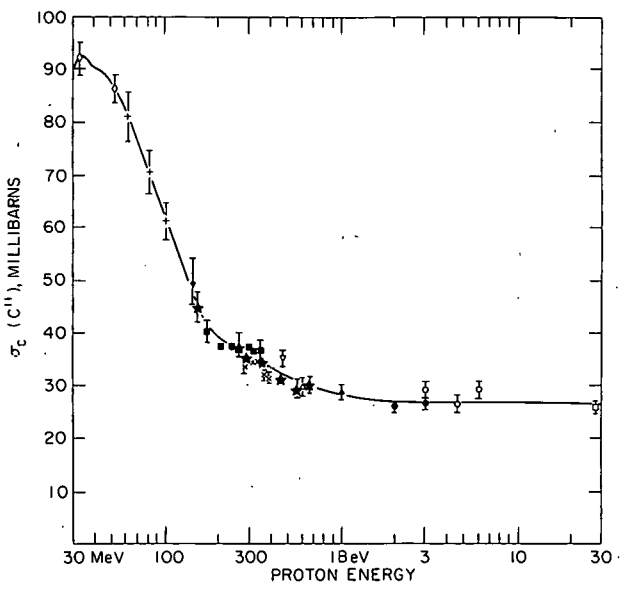


Figure 4. Excitation function for C^{11} production by protons from carbon. The symbols refer to the work of various authors: ◇ – Cumming; + – Hintz and Ramsey; ▼ – Cassels et al.; ★ – Prokoshkin and Tiapkin; ■ – Crandall et al.; × – Parikh; ▽ – Rosenfeld et al.; △ – Goebel et al.; ▲ – Poskanzer et al.; ● – Cumming et al.; ○ – Cumming et al.

Antiproton Interactions in Emulsions

The interaction of 2.9-BeV antiprotons with Ag and Br in nuclear emulsion is being investigated. Comparison of the results with those from a 3-BeV proton irradiation allows examination of the effect of the proton-antiproton annihilation on the following properties: total cross section, multiplicity of emitted particles, energy spectrum and angular distribution of α particles, range distribution of the nuclear recoils, and angular distribution of the recoils with respect to the beam direction and with respect to emitted particles. No striking differences between proton and antiproton induced stars has been observed in the results from preliminary scanning.

Electromagnetic Separator and Spark Source Mass Spectrometer

The High Voltage Engineering Corporation isotope separator has been delivered to the Chemistry Department and passed an extensive testing program. The separator was designed with the objective of versatility in the type of sample to be processed. It has sources capable of handling gases, solids with vapor pressures of the order of microns at 1500°C, and even less volatile solids with comparable vapor pressures at 2500°C. The separator employs a 160-cm-radius 90°-sector electromagnet and can be operated with resolved ion beam cur-

rents in the range 10 to 50 μA. A separation to provide sources of Ag^{108} and Ag^{110} has been carried out on a silver sample that had $\approx$6 weeks' irradiation in the MTR at Arco, Idaho. The operation has demonstrated the utility of the instrument for handling radioactive sources and the relative simplicity of decontamination procedures.

Studies of the high resolution spark source mass spectrometer have been continued to develop it as a special tool for the study of nuclear reactions. The ion source efficiency has been improved to the point where the spark source spectrometer can be applied to the measurement of high energy reaction products. Samples of fission products in U^{235} matrices have been analyzed with the object of accurately determining sensitivity and relative ionization and collection efficiencies of the trace constituents. Partial mass yield curves from U^{235} fission were obtained from samples which contained 15 ppm of the more abundant fission products. These studies showed that analysis of products of nuclear reactions in targets irradiated in the BNL high energy accelerator will require chemical as well as instrumental techniques. Studies are now under way on methods which include one stage of chemical separation of nuclear reaction products from the major constituents of the target matrix. So far, sensitivity which permits detection of 10^{-10} g of rare earth nuclide has been achieved. This sensitivity is adequate for nuclear reaction studies provided that problems of background contamination of target and reagent materials can be solved. These problems are currently under investigation.

LOW ENERGY NUCLEAR REACTIONS

Various studies of low energy nuclear reactions have been continued. Excitation functions for products from the compound nucleus Po^{210} formed either by α-particle irradiation of Pb^{206} or proton irradiation of Bi^{209} have been made with improved precision. Detailed analyses with the IBM 7094 of these and other suitable data from the literature are in progress to investigate the effects of γ-ray emission and angular momentum on excitation functions for nuclear reactions.

The cooperative program with members of the Bell Telephone Laboratories and the Physics Department is being continued to investigate nuclear reactions between relatively simple projectiles and targets at the 60-in. cyclotron. The reactions in the systems He^3+H^2; H^2+H^2; and H^2+H^1 leading to three-body final states have been studied. The formation of particle emitting states in the various possible intermediate nuclei, such as He^4, diproton, virtual singlet deuteron, etc., have been observed to play a significant role. This work has been greatly facilitated by the use of an on-line SDS 910 digital computer for multiparameter analysis and for the calculation and display of simulated experimental data to be expected on the basis of various models.

NUCLEAR SPECTROSCOPY

Internal conversion electrons from odd mass Te isomers have been measured with the high resolution double-focusing β-ray spectrometer. Some mixed transitions, partially magnetic dipole ($M1$) and partially electric quadrupole ($E2$), were investigated. In these cases it is indicated that the $M1$ part represents mainly particle excitation while the $E2$ part represents mainly collective excitation. In the sequence Te^{121}, Te^{123}, Te^{125}, the $E2/M1$ ratio decreases, as does the $E2$ enhancement. The ratios are given in Table 1. This trend is opposite to that predicted recently by one theoretical calculation but agrees with the results of another calculation.

A few M shell internal conversion coefficients in Te^{121m}, Te^{123m}, and Ba^{137m} have been measured and compared with theory. Reasonable agreement is obtained if account is taken of the screening of M electrons by K and L shell atomic electrons. These semiempirical corrections to the theory apply over a wide range of multipolarities, energy values, and nuclear charges.

Preliminary measurements were made of the KLL Auger electrons of Kr^{79}. This source was prepared at the Nobel Institute of Stockholm and measured at BNL with the double-focusing β-ray

Table 1

$E2$ Transition Speeds for the $d_{3/2}\rightarrow s_{1/2}$ Transitions in Te^{121m}, Te^{123m}, and Te^{125m}

Isotope	Energy, keV	$E2/M1=\delta^2$	$\tau(E2)_{s.p.}/\tau(E2)_{exp}$ $=E2$ enhancement
Te^{121m}	212.2	0.050 $\pm$0.003	26
Te^{123m}	159.0	0.0067 $\pm$0.0011	4.5
Te^{125m}	35.3	0.00035	2

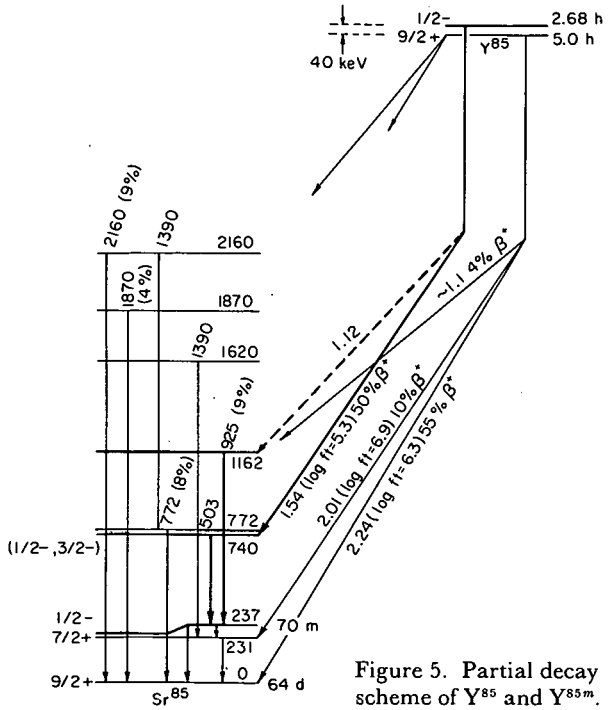


Figure 5. Partial decay scheme of Y^{85} and Y^{85m}.

spectrometer. It was necessary to place a very thin window (0.1 mg/cm²) on the proportional counter to allow transmission of these very soft electrons. All 9 lines, including the 2 KL_3L_3 lines predicted by intermediate coupling, were observed.

After completion of the investigation into the decay of Y^{83} and Y^{85}, whose decay scheme is given in Figure 5, experiments were begun on Rb^{83}. So far it has been shown that the previously reported "single" γ ray at 525 keV really consists of a triplet at 521, 530, and 553 keV. Only the first two transitions are to the 1.9-hr isomeric level of Kr^{83}; the third is to a level 9 keV above the ground state of Kr^{83}. In this work a new lithium-drift germanium solid state detector was used, courtesy of the Physics Department.

SOLAR NEUTRINOS

Radiochemical Detection Systems

The fusion reactions in the sun produce neutrinos which leave the sun with little absorption or energy loss. These particles, which serve as a direct signal from the center of the sun, carry detailed information on the solar energy generation process. This approach to the study of solar energy generation has not yet been explored, since detection systems with sufficient sensitivity have not been developed. An exploratory experiment along these lines must be guided by the results of calculations of solar neutrino fluxes. Sears, Bahcall, and Fowler have recently investigated the solar model calculations and the relevant nuclear reaction data to deduce the neutrino flux and have also evaluated the possible errors associated with these calculations. The neutrino producing reactions and the flux at the earth presented by this group are as follows: $H(H,e^+\nu)D$, $\phi = 5.8\times10^{10}$; $Be^7(e^-,\nu)Li^7$, $\phi = 0.8\times10^{10}$; and $Be^8 \rightarrow Be^{8*} + e^+ + \nu$, $\phi = 1.9\times10^7$ cm^{-2} sec^{-1}. These fluxes are considered to be in error by at most a factor of two.

A pilot experiment was performed in an attempt to observe solar neutrinos by a method based on the reaction $Cl^{37}(\nu,e^-)Ar^{37}$ to form the 35-day radioactive Ar^{37}. The target was 1000 gal of perchlorethylene (C_2Cl_4), and a 2300-ft-deep mine at Barberton, Ohio, was chosen as the irradiation area so that the target would be shielded from cosmic rays. A low level counting system for Ar^{37} was developed that has a high sensitivity for the characteristic 2.8-keV Auger electron from Ar^{37} decay. The present system has a background of <1 count in 10 days. Measurements with this counting system were done on samples from the 1000-gal apparatus in the Barberton mine. From these observations the solar neutrino capture rate was concluded to be <0.5 per day in the 1000 gal of C_2Cl_4, a limit close to the forecasted rate of 0.07 per day. The limit set was of value in eliminating from consideration certain reactions postulated in the past as contributors in the solar energy generation process.

The performance of this small-scale experiment showed that the method could be extended in sensitivity sufficiently to measure the calculated solar flux, and that background effects from cosmic radiation and local radioactivities could be reduced to

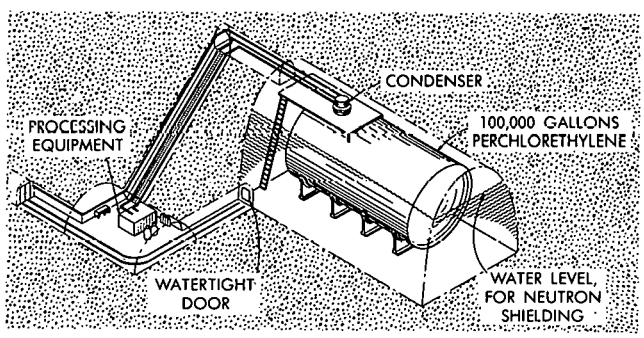


Figure 6. Brookhaven solar neutrino observatory.

a factor of 100 below the calculated neutrino signal. Plans are under way to increase the sensitivity of the method by working with a 100,000-gal detector, and design studies were made of this larger apparatus. Design of the physical arrangement in the mine (shown schematically in Figure 6) was based on considerations of the shape and size of a cavity that could be excavated and supported in a deep mine. A method of agitating and purging the liquid with helium in a tank 20 ft in diameter and 45 ft long has been tested on a small scale. Two mines suitable for the apparatus have been located, and discussions with the owners have established that either could be made available for the neutrino experiment.

Low Level Fast Neutron Detector

A fast neutron detector has been developed, based on the $Ca^{40}(n,\alpha)Ar^{37}$ reaction, that is capable of observing fast neutron fluxes $<10^{-6}$ neutrons/cm^2-sec. This detector was used to evaluate the background effect from fast neutrons produced in the mine from small amounts of uranium and thorium contained in the surrounding rock wall.

NUCLEAR GEOCHEMISTRY

Lead Isotopic Abundances of Archaeological Specimens

A new method for determining the place of manufacture of ancient lead-containing metal or glass objects based on a lead isotopic abundance measurement has been developed in cooperation with the Corning Museum of Glass. The method is based on the fact that lead ores from different localities have differing isotopic abundances because of differences in their geological histories. For example, objects made from lead mined in Great Britain show a lead isotopic abundance distinctly different from that of objects made from lead mined in Greece.

Lead metal was used in a variety of ways in ancient civilizations because of its easy workability and resistance to corrosion. Lead is also an important constituent of pottery glazes and decorative glass. Some of this lead came from small ore deposits in the central Mediterranean region, but in later times the Phoenicians and Romans obtained lead from larger deposits in southern Spain and from as far away as Great Britain.

Of all the chemical elements, lead is the only one which shows large changes in isotopic composition from place to place in the earth; that is, the relative amounts of the isotopes Pb^{204}, Pb^{206}, Pb^{207}, and Pb^{208} are not fixed. For example, a sample of lead from the Witwatersrand in South Africa contains twice as much Pb^{206} as a sample from the Pretoria district. These variations occur because three of the isotopes – Pb^{206}, Pb^{207}, and Pb^{208} – are produced as a result of the radioactive decay of natural uranium and thorium and therefore increasing amounts of these isotopes are continually being mixed with the lead present since the earth was originally formed.

In most cases the variations from one locality to another are much smaller than in the above example, but small variations in isotopic composition may be measured with a mass spectrometer. Studies have been made on a number of samples of lead ore, as well as lead objects made from the ore, from an ancient mine in Greece and from several ancient mines in England and Wales. The

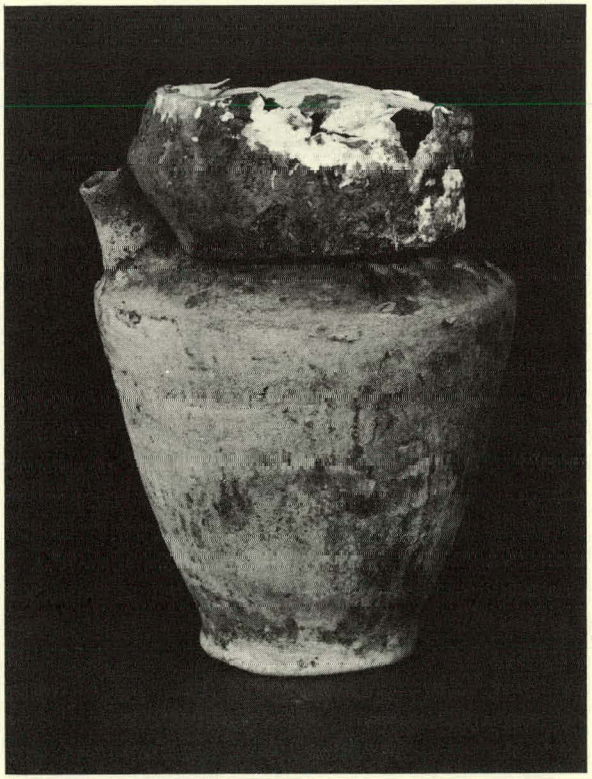


Figure 7. Pottery jug with lead cover from Jemdet Nasr, Ur, *ca.* 3000 B.C. (Courtesy Prof. Robert Dyson, University Museum, Philadelphia, Pa.)

samples from Greece are distinctly higher in Pb^{206} than those from Great Britain. The samples from England contain more Pb^{206} than those from Wales. With this information, isotopic analysis should help an archaeologist determine the origin of the lead in a particular sample. A thorough study might be able to show the extent to which the Romans transported lead from Great Britain to Italy and to reveal other information about commerce thousands of years ago. Work with lead isotopes should provide an independent approach in the archaeological studies carried out here in recent years, which depend on activation and chemical analyses of key trace elements.

METEORITE STUDIES

Cosmic-Ray Flux in Space

The spatial variation of cosmic-ray intensity can be determined by measuring short- and long-lived activities induced in meteorites. The short-lived activity measures the cosmic-ray flux close to the earth and requires fresh dated fall meteorites. Long-lived activities integrate over a time comparable to the half-life of the induced activity. Most of this time is spent while the meteorite is distant from the earth. Such measurements require samples of known trajectory or orbit.

The two isotopes of argon, Ar^{37} (35-day half-life) and Ar^{39} (270-yr half-life), are ideally suited for this purpose. The activity ratio Ar^{37}/Ar^{39} is observed on the meteorite immediately after its fall. The observed ratio is then compared with the same ratio for these isotopes measured with high energy protons on meteoritic material at the Brookhaven Cosmotron. During the past year two new meteorites have been investigated. However, the most important result was the revised half-life of Ar^{39}, which changes the interpretation of our previous results. The result of these studies with the 270-yr half-life, except for the meteorites Hamlet and Ehole, which show the effects of intense solar flares, is that the Ar^{37}/Ar^{39} ratio is lower than the cross section ratio. This shows that the cosmic-ray intensity at the earth is lower than the intensity 200 to 300 million miles from the earth. The diminished cosmic-ray intensity near the earth could result from the outstreaming solar plasma. The sun spot number serves as a measure of the plasma emission from the sun. The coming year is expected to be a period of minimum solar activity, and the Ar^{37}/Ar^{39} ratio is expected to increase, perhaps approaching the value of the cross section ratio.

Exposure Ages

Work in the past year has been devoted to Ar^{39} activity and rare gas measurements on samples of the various classes of meteorites. In particular, metallic iron was separated from meteorites so that samples of uniform chemical composition were available for measurement. This procedure affords an easy comparison between the meteorite classes and with high energy proton bombardments on iron targets. The particular problem is to ascertain the time meteorites have been exposed to cosmic radiation in space. This is done by comparing a radioactive cosmic-ray produced nuclide such as Ar^{39} to a stable cosmic-ray produced nuclide, of which good examples are He^3, Ne^{21}, Ar^{36}, and Ar^{38}. The radioactive nuclide is a measure of the cosmic-ray intensity over the mean life of the nuclide, and the stable nuclide integrates the total cosmic-ray flux. Measurements on chondrites, which are by far the most common class of meteorites, are given in Table 2. They indicate that the chondrites have been in space for time periods ranging from 3 to 40 million years, although one extreme case gave an exposure of 15,000 years or less. There is no evidence for a grouping of exposure ages, which suggests that chondrites were formed by continuous collisions of larger bodies rather than by a small number of catastrophic events.

Helium-Uranium Dating of Fossils

One of the major problems in geochronology is the dating of fossils. The geological time sequence from early Cambrian to recent is well defined relative to the fossil record in ancient layered sediments. At present, such absolute dating of the fossil time scale is primarily accomplished by dating of granitic rocks, which are then related by field studies to sedimentary sequences. Unfortunately, cases in which such a relationship can be precisely and unambiguously defined are quite rare. In addition, many geological situations arise in which not even a remote relationship between sediments and datable phases can be established (e.g., the ocean basins, where no granites occur). In such sedimentary sequences dating via igneous phases is usually impossible. In relatively young sediments ($<10^7$ years) there are seldom enough igneous

Table 2

Ar^{39}-Ar^{38} Exposure Ages of the Iron Phase of Chondrites

Meteorite	Exposure age, millions of years
Beardsley	5.0
Cape Girardeau	32
Forest City	5.0
Bjurhole	13
Peace River	29
Harleton	39
Farmington	<0.4
New Concord	2.0
Bruderheim	27
Abee	5.1

Table 3

Comparison of He-U Ages of Fossils With Th^{230}-U^{234} and Stratographic Control Ages

Sample	Age, thousands of years	
	He-U	Control
Pacific coral		
50 ft deep	120± 20	107± 10
85	175± 30	155± 15
100	370± 60	330± 50
700	8000±2000	12000±2000
950	17000±3000	15000±3000
2000	26000±4000	23000±3000
Gastropod shells		
Israel	405± 50	360± 60
Nevada	440± 60	400± 150
Nevada	500± 60	400± 150

phases available to define time sequence, and the last 10 million years (especially the last 1 million) are of extreme interest to geologists.

It has been found that aragonitic fossil shells and corals usually contain a few ppm of uranium and, in addition, that the He^4 produced by this uranium and daughters is retained in the aragonite lattice for periods of 1 million years and probably for periods of up to 30 million years. This conclusion is based on comparison of He ages with Th^{230}/U^{234} ages on shells and corals $<3\times10^5$ years old and by comparison with age estimates based on stratographic position for corals up to 30 million years old. From the data in Table 3 it appears that the He method probably is a practical geochronometer for the direct dating of fossils. This work was done in collaboration with the Lamont Geological Observatory (Columbia University), which provided the Th^{230}/U^{234} age control.

AUTORADIOGRAPHY OF OIL PAINTINGS BY NEUTRON ACTIVATION

The art conservator has benefited greatly by being able to look through an object with x rays and perceive details of its inner structure, even though the details so revealed are limited to differences in physical thickness or in the distribution of atoms of relatively heavy atomic weight. In examining an oil painting the conservator might well regret the inability to perceive placement of lighter atomic weight pigments whose distributions are likely to be obscured. A particularly unfortunate situation in the conventional radiography of oil paintings arises when an electronically dense pigment such as white lead has been used in the ground, because the dense absorption of the ground layer can almost completely mask the details of the layers of the design. A probable example of such an occurrence is shown in Figure 9, in which a photograph of a portion of a 17th century painting is compared with an x radiograph of the same area. The details of the radiograph appear to be primarily only those of the support and ground. Figure 10 presents several contrasting radiographs of the same painting fragment pro-

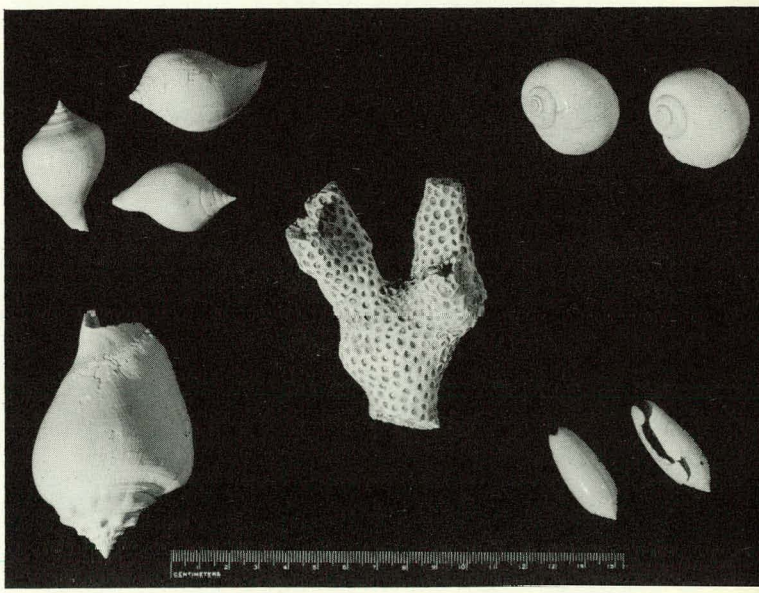


Figure 8. Fossil aragonite shells and coral suitable for He-U dating.

duced by nuclear activation autoradiography. It is immediately apparent that the neutron radiographs, although they greatly resemble conventional x radiographs, provide considerable additional information. The different pictures in this figure only in part exemplify the variety of characteristically different autoradiographs of this painting that potentially might be produced through variation in the autoradiographic procedure.

Different autoradiographs are obtained by taking exposures at different times following activation, by interposing appropriate filters between the painting and the film, and by varying conditions of activation. It is a fortunate coincidence that many of the components of colored pigments, e.g., copper, manganese, cobalt, mercury, arsenic, and the aluminum or barium present in the mordant of lake pigments, are activated very effectively by thermal neutrons, while the components of the common white pigments and the organic material comprising most supports are relatively ineffectively activated. The analysis of the entire series of autoradiographs, each differing from the next, that can be made from one painting, provides information about the pigment composition and distribution throughout the painting. In comparing the two upper autoradiographs in Figure 10 it is apparent that the one on the left tended to be dominated by radiation from pigments used in the foliage constituting the painting foreground, whereas the one on the right primarily arose from pigments constituting the background behind and to some extent beneath the foliage. It would appear that the artist left free of background pigment a large fraction of the lower left area in which he intended to place the foliage. However, when he later added the foliage, he at some places painted over the region in which he had placed background. In this instance the basic approach of the artist in the application of pigment layers has in part been revealed.

Other methods and conditions of activation and other means of registering the radiation from the painting should produce yet additional significantly different autoradiographs. Most promising among these variations would be (1) scanning of the activated painting by counting equipment which can be considerably more selective in its

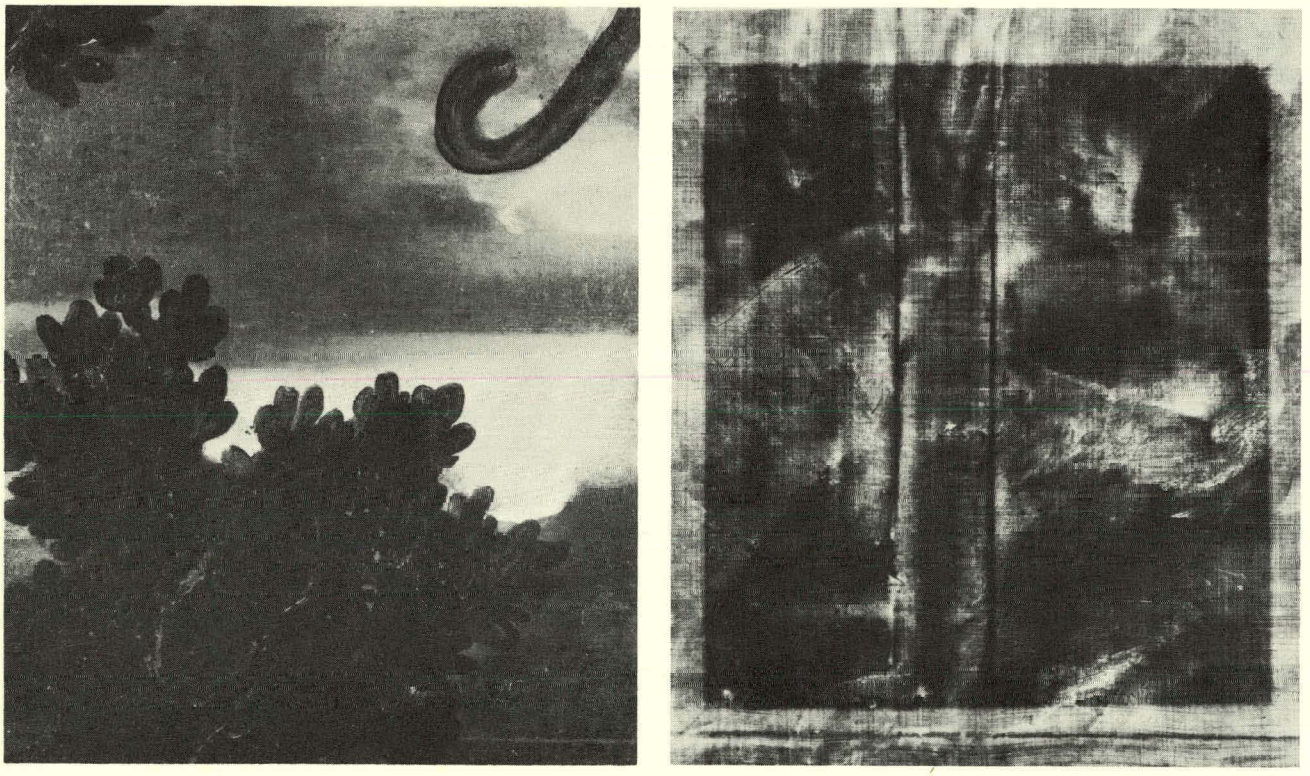


Figure 9. Conventional radiograph (right) of part of a 17th century Dutch painting (left).

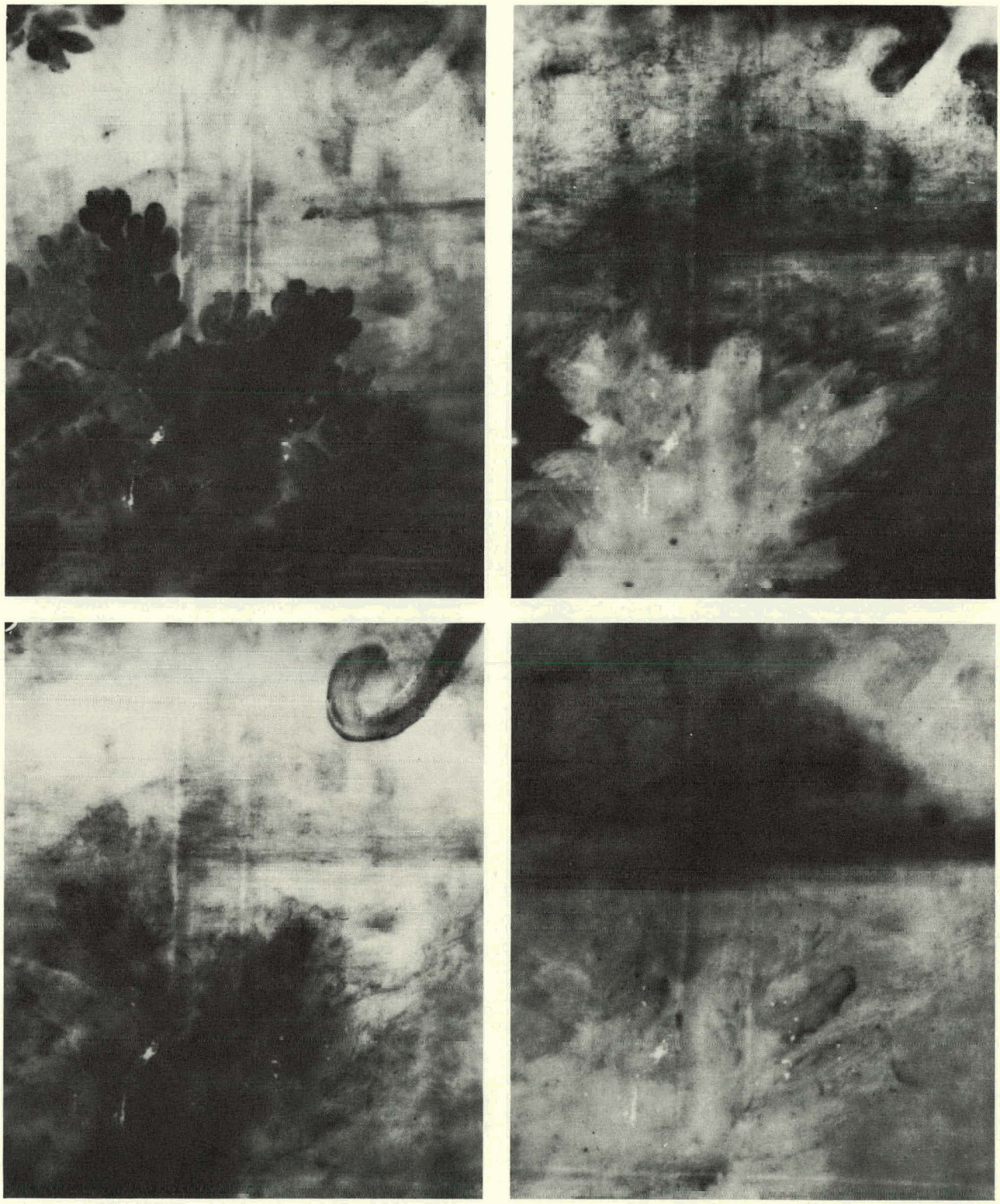


Figure 10. Four neutron activation autoradiographs of the same painting as in Figure 9. Since these were taken at different times after irradiation, they highlight different pigments.

response to individually different types of radiation than photographic emulsions, and (2) activation by fast neutrons.

At its present stage of development, the technique of neutron activation autoradiography of oil paintings can be considered as a successful method of analysis which does not require the taking of samples, and, when further developed, it promises to supply the conservator with a large body of information about an individual painting before any treatment is initiated. Indeed, it should greatly facilitate the planning of a course of treatment for the work of art. This method permits the examination of a painting in depth, hopefully without altering it in any significant way, and affords the conservator an insight into the materials, structure, and some of the techniques originally used in its creation.

RADIATION AND HOT ATOM CHEMISTRY

Radiolysis in the Adsorbed State

The γ-ray decomposition of azoethane adsorbed on the surface of inert mineral solids is being investigated. Azoethane is chosen because formation of nitrogen gas from this compound requires relatively little energy while methane and hydrogen may be formed from states of higher energy. It is found that considerable decomposition of the organic material occurs by energy taken up from the radiation by the solid and transferred in some way through the solid and then to the organic molecule adsorbed on its surface. The results are interpreted in terms of the interaction of excited electronic states of the solid with the organic molecule. With azoethane adsorbed on silica gel, the amount of decomposition products increased as expected with the amount of azoethane present. However, on magnesium oxide prepared by thermal decomposition of the basic carbonate, the amount of each gaseous product reached a maximum and then declined with increasing azoethane coverage. The position of the maximum depends on the ignition temperature of the oxide and appears at lower coverage, the lower the ignition temperature. The adsorbate molecules are thought to interact with a surface state which can draw excitation energy from a considerable volume of the solid. On magnesia, the data appear to suggest that the available energy is divided among the molecules present, so that at low coverages some molecules are raised to high states of excitation whereas at higher coverages only states of lower energy are formed. It is found that color centers formed by irradiation in silica gel are bleached by simple contact with azoethane. This type of study offers a unique approach to the problem of energy transfer within solids, as well as from a solid surface to an adsorbed molecule.

Ion Yield in Liquids

The number of ions formed at zero applied field by irradiation of a liquid with x or γ rays has been determined for the first time by methods which appear to be, in principle, straightforward and theoretically unobjectionable. Measurements of four quantities are required: (1) conductivity of the liquid extrapolated to zero field, as a function of radiation intensity; (2) ion recombination coefficient, by rate of current decay when radiation is switched off; (3) drift mobility of the positive and negative ions; (4) radiation "dose," or energy input to the liquid. In hexane, 1000 eV are expended per ion pair formed when the agent producing the ionization is a Compton electron of energy around 0.5 MeV, while with conversion electrons from dissolved Ar^{37} having an energy of only 2400 eV, about 2000 eV are required per ion pair. The yield of ions in the liquid is only about 2% of the number formed in the vapor. Similar results were obtained with carbon tetrachloride. These results contrast with the situation in water, where the yield of solvated electrons has been shown to be practically equal to the yield of ions in water vapor. An attempt is being made to extend the conductivity measurements to ethers and other liquids of intermediate polarity.

Lifetimes of Intermediates

Apparatus, which includes the Van de Graaff electrostatic generator as a source of radiation, has been set up for the spectroscopic study of intermediates of lifetimes down to a few microseconds. Studies have been started on the intermediates formed in radiolysis of oxygenated ferrous salt solutions in water and solutions of electron-capturing substances in organic solvents.

Solvated Electrons

Studies on competitive systems of mixed scavengers in water are being continued in an effort to understand why certain systems seem to indicate a higher yield of solvated electrons produced in neutral water than do other systems. The yield

of neutral hydrogen atoms, apparently formed along with the electrons, has been determined in several systems. The reaction between ethanol and hydrogen peroxide in dilute solution has been shown to proceed by a chain reaction, the mechanism of which has been worked out in detail.

Carbon-14 Recoil Studies in Acetamide

Work on acetamide using the $N^{14}(n,p)C^{14}$ reaction has been extended to very low radiation doses. Very short contact times in the reactor ($\approx$1 min) were used. The low level of activity produced in such short times was assayed by means of low level counting facilities now available at BNL. Activities assayed as acetic acid (hydrolysis of acetamide) and acetone (recoil replacement of an NH_2 group in acetamide) were found to increase markedly as the radiation dose was reduced. Yields of labeled acetonitrile and acetamide were essentially unaffected in the range studied (2×10^{-3} to 10 eV/molecule). In addition, only small differences in yields were found when different crystalline states or phases were irradiated. No appreciable annealing effect could be observed. The use of fractional fusion as a purification technique for recoil labeled materials was extensively studied in this work and was shown to be highly effective in some systems.

Carbon-11 Reactions in Alkanes, Nitrogen, and Cylic Hydrocarbons

The effect of oxygen on major products from the reaction of "hot" C^{11} with gaseous alkanes was studied with oxygen concentrations up to 23 vol %. A rapid increase in CO yield at very low O_2 concentrations followed by a much slower and linear rise indicates a fast thermal reaction which quickly reaches a saturation value. A reaction between the thermalized carbon atom and oxygen seems reasonable. The subsequent slow increase in CO along with a concomitant decrease in acetylene and ethylene suggests a competition between O_2 and the substrate alkane for the hot carbon atom (and perhaps also methyne, $\cdot\dot{C}H\cdot$). A simple kinetic treatment fits the observed facts and indicates that the reaction probability for reaction between the carbon atom and oxygen to give CO is about three times as great as for the reaction between the carbon atom and the alkane to give acetylene.

The reactions of energetic carbon atoms with nitrogen have also been studied under a variety of conditions. Recoil range studies on C^{11} as a function of total gas pressure have been carried out for the p,α and $n,2n$ reactions. The three major products in nitrogen-alkane mixtures have been shown to be acetylene, ethylene, and hydrogen cyanide. The alkanes used were ethane, propane, and the corresponding perdeutero compounds. Yields of each of these three products have been determined as a function of (a) nitrogen-alkane ratio, (b) absorbed energy during nuclide formation, (c) oxygen concentration at various ratios of alkane to nitrogen, and (d) presence of the inert moderators, helium, neon, argon, krypton, and xenon. A pattern similar to that observed in pure alkanes is found. The formation of HCN is considerably less sensitive to O_2 than the formation of either acetylene or ethylene. The noble gases, helium, neon, and argon, are found to behave similarly after correction is made for their mass and energy absorbance, but krypton and xenon show marked but dissimilar effects. Moderation experiments also show acetylene yields to be considerably more sensitive than ethylene yields.

In connection with the reactions of energetic carbon atoms with alkanes, work on acyclic saturated hydrocarbons has continued, and determinations have been completed on compounds through C_5 plus a few C_6 compounds. In addition, the C_3 to C_6 alicyclic hydrocarbons have also been studied. The structural dependence of the yield of ethylene was found to be consistent with the postulate of hot insertion reactions by $\cdot\dot{C}H\cdot$ (methyne) formed while the carbon atom is thermalizing. The relationship

$$\text{yield of ethylene} = k\frac{\sum \text{primary hydrogens in molecule}}{\sum \text{total hydrogens in molecule}}$$

is strictly obeyed for all C_1 to C_6 acyclic saturated hydrocarbons thus studied. The yield of ethylene from C_3 to C_6 alicyclic hydrocarbons is seen to be equal to the value obtained by extrapolating the plot of yield versus the above hydrogen ratio to zero value for the ratio.

Spin State of Methylene

Insertion reactions by hot methylene were first suggested in 1956 as a mechanistic rationale for the reactions obtained by allowing hot carbon atoms to thermalize in organic substrates. The spin state of this hot methylene has now been determined by applying the criterion of stereoselective synthesis. Methylene-C^{11} reacts with *cis*- and *trans*-2-butene to produce the corresponding *cis*- and *trans*-1,2-di-

methylcyclopropane almost exclusively, thus establishing the hot methylene to be in the singlet (first excited) state.

Specific Radiation Synthesis of Alcohols

The high yield of propanol-C^{14} from recoil reactions in the NH_3-CH_3OH system led to the prediction that propanol-C^{14} could be produced in good yield by nuclear reactor irradiation of solutions of ethylene in CH_3OH for periods of the order of one day. The first experiment confirmed these predictions, and symmetrically labeled propanol-2,3-$C_{,}^{14}$ was produced in 40% yield based on ethylene. Similar experiments with methanol-propene-1-C^{14} mixtures gave 70 to 80% chemical yields of specifically labeled isobutanol. The absence of *n*-butyl suggests as the mechanism a fast addition of a radiolytic hydrogen atom to propene followed by radical recombination with hydroxymethylene radical. These radiolytic syntheses are simple and convenient methods for the preparation of the labeled compounds.

Bromine Recoil in Hexabromoethane

An extensive investigation has been made of the annealing of recoil Br^{82} in crystalline hexabromoethane following neutron exposure at $-196°C$. The interaction between radiation defects and recoil atoms in the crystal was investigated over a large range of radiation doses (0 to 20 Mrad) and temperatures (-80 to $+120°C$). Clear evidence was obtained for a multiplicity of annealing processes, having distinct activation energies, in the very low dose region (a few roentgens); these have been designated the "intrinsic" annealing processes. The activation energies and Arrhenius frequency factors of two of these intrinsic processes were obtained: their kinetics were first order.

When small doses (up to about 1000 R) of radiation were applied to the crystals, the process having the highest activation energy for "intrinsic" annealing showed an extraordinarily sensitive response; its acceleration could be clearly seen with doses even as low as 10 to 20 R. With further increase in radiation dosage a complicated pattern of interaction between defects and recoil atoms emerged, the over-all trend being the influencing of processes having lower and lower temperature ranges (and, by inference, activation energies).

When differing intensities of radiation were employed to produce the same total dose, differences in the subsequent thermal annealing of the Br^{82} atoms appeared, suggesting that transient species, produced by radiation, could interact with one another before decay. Taken together, these results demonstrate that the thermally stimulated interaction of radiation defects and recoil atoms in an organic crystal has a complexity hitherto unappreciated.

MOLECULAR AND CRYSTAL STRUCTURE

Magnetic Structures

The magnetic structures of several intermetallic compounds, in which the components are rare earth and transition metals, have been determined by neutron diffraction. The ferrimagnetic nature of $HoCo_5$, inferred by other workers from systematic trends in the saturation moments of the isomorphous rare earth series, has been confirmed by neutron diffraction. A study of the isostructural compound $ErNi_5$ supports the supposition that in the nickel–rare earth series the three valence electrons of the rare earth metal just fill the holes in the 3*d* bond of the nickel, which results in zero magnetic moment for the nickel.

Investigation of the first-order transition in $MnSn_2$ and its accompanying magnetic transition has been extended by the study of the effect of partial substitution of indium for tin. The two magnetic phases previously associated with the temperature regions above and below the first-order transition in pure $MnSn_2$ have been shown to coexist above the transition temperature in the substituted compound.

The antiferromagnetism of $MnSe_2$ was reinvestigated following a suggestion in the literature that this compound might provide a test of the Landau-Lifshitz theory of second-order phase transitions. The temperature dependence of magnetic scattering intensity was found to exhibit an unusual abrupt transition from short-range order to well developed long-range order. The radical departure from Brillouin behavior makes it unlikely that the theory of second-order transitions would be applicable to this case.

Atomic Charge Distribution in Fe_4N

The development of the modern x-ray diffractometer, using a scintillation counter, has made it possible to determine the electron charges of atoms in crystals by measuring reflection intensities at small scattering angles.

A powder sample of Fe_4N was examined in order to determine the electron charge on nitrogen. Fe_4N has a moment of 8.86 Bohr magnetons per Fe_4N or 2.2 β per Fe, the same as pure iron. The crystal structure is cubic with closest packing of Fe. The atomic positions are Fe: 000; $\frac{1}{2}\frac{1}{2}0$; $\frac{1}{2}0\frac{1}{2}$; $0\frac{1}{2}\frac{1}{2}$; and N: $\frac{1}{2}\frac{1}{2}\frac{1}{2}$. Thus nitrogen is nearest the face-centered irons and somewhat more distant from the iron occupying the cube corner. Two distinct and different electron configurations consistent with this structure and a total magnetic moment of 9 Bohr magnetons have been proposed by Wiener and Berger and by Zener. In the Wiener-Berger model each nitrogen atom donates one electron to each face-centered iron atom. Zener's model has face-centered iron cations and N^{3-}. Neutron diffraction measurements by Fraser have shown Fe_4N to be ferromagnetic and were interpreted in favor of the Wiener-Berger model. Inasmuch as N^{3+} seems unlikely in a metal nitride, the problem has been investigated by the x-ray diffraction method.

The presence of nitrogen in the Fe_4N lattice gives rise to "superlattice" lines, the 100 and 110 reflections. These reflections occur at sufficiently low angles that a significant contribution is made to the intensities by the outer electrons of nitrogen. Hence it was possible to reach a conclusion regarding the nitrogen electronic charge by comparing observed and calculated "superlattice" reflections, together with the "normal" reflections for different states of ionization of nitrogen. In this experiment it could only be concluded that nitrogen is somewhat more negatively charged than N^{1-} because there are no calculated scattering factors for N^{2-} and N^{3-}.

If one assumes the simple Wiener-Berger model to be correct, the neutron and x-ray diffraction results are compatible only if one further assumes some degree of covalency to bring about the electron spin alignment of this model.

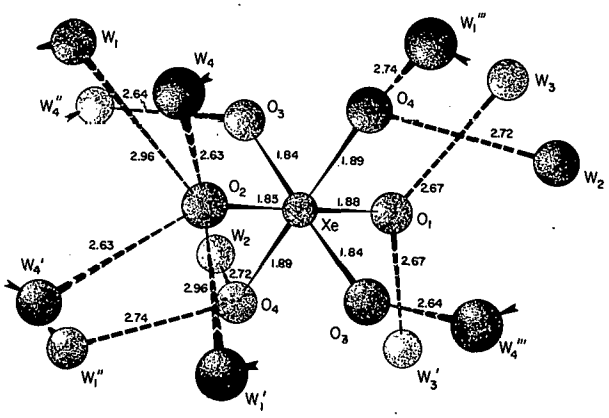


Figure 11. Perxenate ion with surrounding water molecules. A twofold axis coincides with the line O_1-Xe-O_2. The dashed lines are hydrogen bonds. The sodium ions coordinated to the perxenate ion and the water molecules are not shown.

Automated Diffractometry

The automatic data collecting devices for neutron diffractometers mentioned in last year's report have been successfully collecting data for several months, and computer programs have been developed for preparing and processing the paper tapes which are input and output for these devices.

Structure of Perxenate and Tellurate Ions

The work in xenon chemistry continued with the characterization, through x-ray diffraction techniques, of the crystalline product formed when XeF_6 reacts with aqueous NaOH. Characterization by conventional techniques was ineffective, partly because of a lack of knowledge of xenon chemistry. The product was found to be sodium perxenate octahydrate, $Na_4XeO_6 \cdot 8H_2O$. The perxenate ion resembles the periodate ion geometrically and presumably in its physical and chemical properties. The structure consists of regular octahedra with a Xe—O distance of 1.865± 0.012 Å. The perxenate ions are extensively hydrogen bonded by the water molecules in the crystal. The structure is shown in Figure 11. The structure of potassium acid tellurate, $KTeO(OH)_5 \cdot H_2O$, has been determined. The tellurate ion has been shown to be similar to the perxenate ion. The structure shows one Te—O distance of 1.83 Å and 5 Te—O bonds of 1.92 Å. These are interpreted as the Te—O and Te—OH bonds respectively.

S—O Bond Length

The determination of the crystal structure of the methyl ester of *o*-nitrosulfenic acid has led to the first measure of the length of the S—O single bond and has explained the stability of the compound by indicating a weak intramolecular bonding between the sulfur atom and one of the oxygen atoms of the nitro group. The structure is shown in Figure 12.

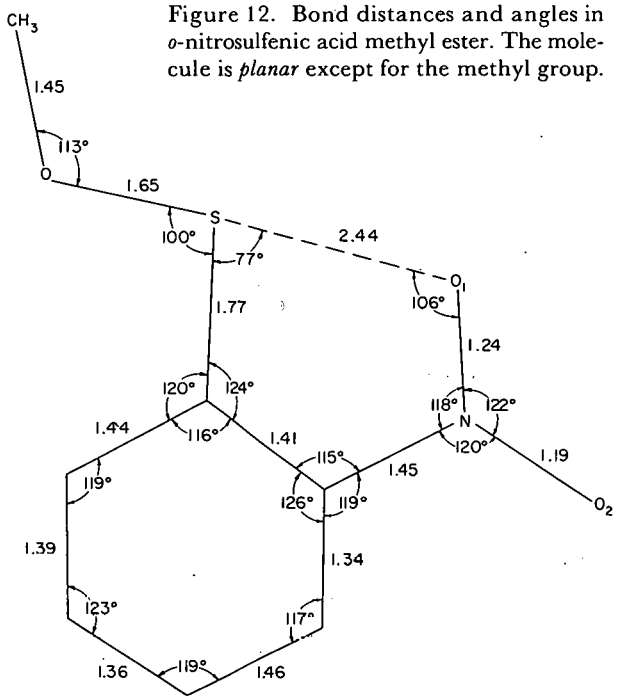


Figure 12. Bond distances and angles in *o*-nitrosulfenic acid methyl ester. The molecule is *planar* except for the methyl group.

Configuration of Guanylhydrazone

The crystal structure of an antileukemia drug has been studied in order to provide pharmaceutical chemists with the configuration of the molecule. The substance is methylglyoxal bis(guanylhydrazone); the conjugated C—N chain of the molecule has been shown to have the *anti-anti* configuration. The final bond distances and angles await refinement of the anisotropic thermal parameters now in progress.

Inorganic Hydrates

The structures of a number of inorganic hydrates, $MgSO_4 \cdot 4H_2O$, $MgSO_4 \cdot 7H_2O$, and $FeSO_4 \cdot 7H_2O$, have been completed. The role of water in the crystallization in these systems and the nature of the hydrogen bonding have been studied.

Hydrogen Bonding and Metal Hydrogen Bonds

Efforts in the study of hydrogen bonding continued with the refinement of neutron diffraction data on KHF_2 and with the development, by combination of the diffraction and spectroscopic data, of a suitable potential function for the stretching region in potassium acid fluoride. Both the neutron diffraction and spectroscopic data are consistent with a symmetric hydrogen bond in KHF_2 and KDF_2.

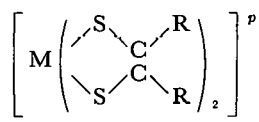
Nonstoichiometric Oxides

The structure of the hydride $HRh(CO)[P(C_6H_5)_3]_3$ has been determined to a very high accuracy, and the H—Rh bond length characterized. The Rh—H bond has been determined to be 1.60 ± 0.12 Å. The rhodium is near the center of a trigonal bipyramid as shown in Figure 13. Significant features of this study are the determination of the geometry of five-coordinated rhodium and, more important, the finding that the Rh—H bond is of normal length. There are arguments in the literature that the transition metal–hydrogen bond is abnormally short, but these are all based on indirect information. That the bond is of normal length, if a general result, is extremely important to the whole of metal hydride chemistry, particularly since this hydrogen plays a crucial role in a variety of reactions, such as hydroformylation. Proposed mechanisms attempt to take account of the strength of the bond.

The structural analysis of $HMn(CO)_5$ has been completed. In complete disagreement with the indirect infrared analysis, $HMn(CO)_5$ was found to have C_{4v} symmetry.

Structure of Bis(maleonitriledithiolato)nickelate(II) Ion

Compounds containing the anion



with $p = -1$ or -2 and M = Ni, Co, Pd, etc., show unusual magnetic properties. There has been much controversy concerning the bonding of these compounds, but no structure determination on which to base the arguments. The structure of the -2 anion (containing Ni) has been determined and shown to be square planar with the Ni—S—C lying in a plane. The symmetry of this part of the ion does not differ significantly from D_{2h}. The energy states of the ion have been calculated in the ligand field approximation of the molecular orbital (MO) method. The electronic spectrum has been assigned, and the lowest transition in the visible is attributed to a charge transfer band from the metal ion to the ligand. The ultraviolet band at 31,700 cm^{-1} is a ligand-ligand transition analogous to the band of the uncoordinated maleonitrile at 29,500 cm^{-1}. A strong ligand to metal charge transfer band appears at 37,000 cm^{-1} and a weaker one at 26,300 cm^{-1}.

Theory of Structural Analysis

Interest in the theory of structural analysis continues. In particular, a new treatment of anomalous dispersion effects has been derived that seems more tractable than those proposed previously. Also, refinement of the structure of dibenzene chromium, in which the benzene rings were constrained to their normal symmetry, has shown that the usual tests of significance of differences in bond lengths must be applied with caution.

ISOTOPE EFFECTS

Computer Calculations of Equilibrium and Kinetic Isotope Effects

During the past year, digital computer programs have been set up which make possible the calculation of equilibrium (kinetic) isotope effects corresponding to given force field assumptions for reactants and products (transition states). These programs first calculate the normal vibrational frequencies and then use these to evaluate the relevant partition function ratios. In the past, the calculation of vibrational frequencies with a hand calculator has been very difficult. Consequently approximation procedures for isotope effect calculations have been developed which bypass the calculation of vibrational frequencies. It has now become possible to test these approximation procedures and to find their limits of applicability. Further insight into the "structure" of isotope effects has been obtained. Indications have been obtained that the isotope effects for very large molecular systems can be studied theoretically by working with smaller model molecules ("cutoff

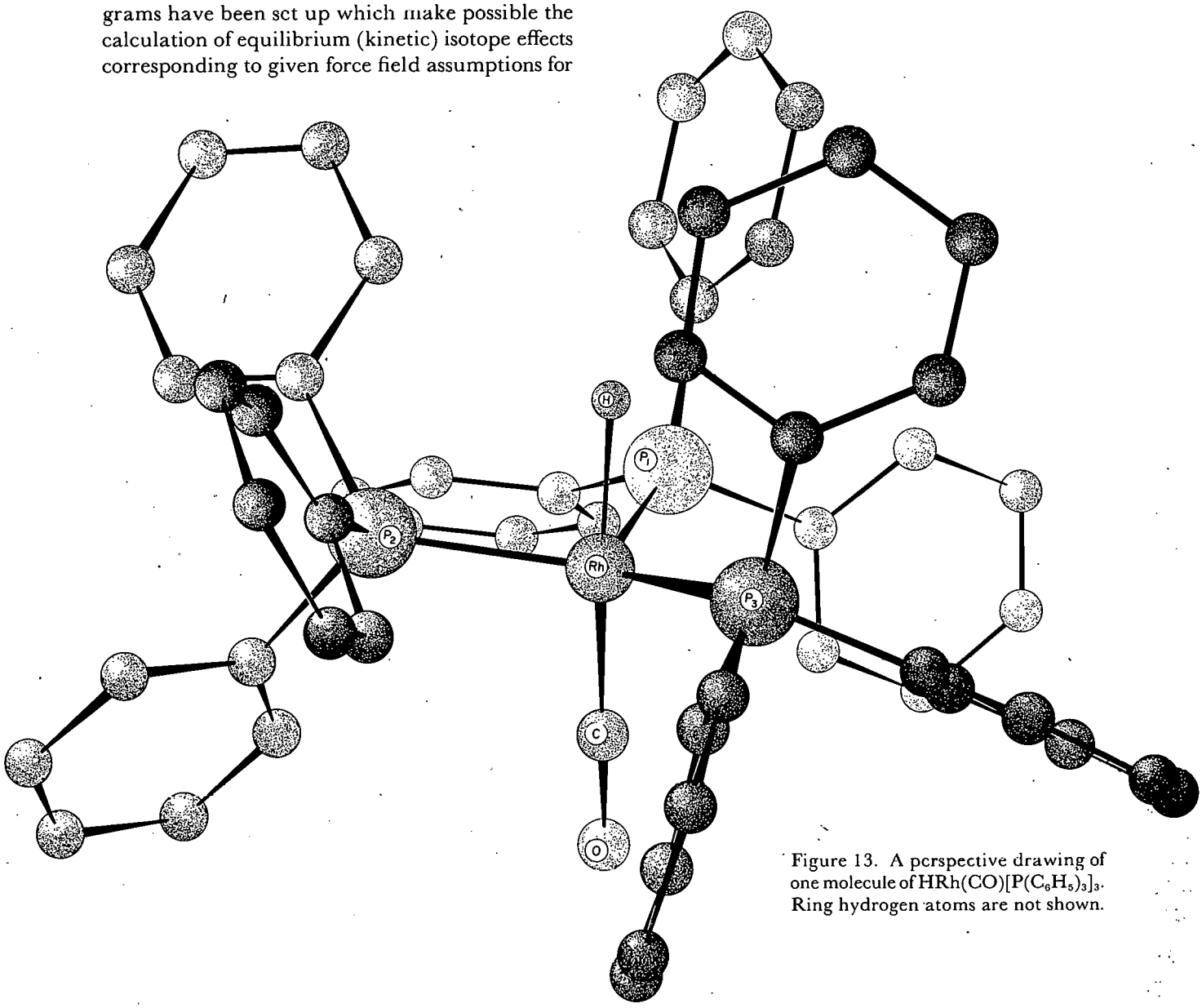


Figure 13. A perspective drawing of one molecule of $HRh(CO)[P(C_6H_5)_3]_3$. Ring hydrogen atoms are not shown.

procedure"). The programs have also been used to elucidate further the nature of secondary isotope effects (in particular secondary hydrogen isotope effects). It has been shown that secondary kinetic isotope effects should be quite small in the absence of force changes (between reactant and transition state) at the isotopically substituted position(s) and that geometry changes are fairly unimportant. Secondary isotope effects may thus be taken as probes for such force constant changes.

Translation-Rotation-Vibration Coupling in Condensed Phases

It has previously been proposed that the restriction of the rotational and translational motion of molecules in the condensed phase will lead to interactions between these motions and the internal vibrational motions, and that these interactions will lead to vapor pressure isotope effects. The theory of these interactions has been further explored, and application has been made to the case of the liquid isotopic ethylenes. Let B designate the zero-point energy change of the internal frequencies of a given isotopic ethylene on condensation minus the corresponding change in C_2H_4. The isotopic vapor pressure measurements previously carried out at this Laboratory show that the ratios $B_{C_2H_2D_2}/B_{C_2H_3D}$ for the three dideutero ethylenes (*cis*, *trans*, *gem.*) differ from 2.0 and from each other. The above described interactions permit rationalization of these B ratios. Force fields have been constructed for liquid ethylene which yield almost quantitative agreement both with the vibrational spectral data available for the liquid and with observed vapor pressure isotope effects (including C^{13}). These latter calculations were again carried out with the help of a digital computer.

A number of years ago some experiments were carried out jointly with LASL to measure the Henry's law constants of dilute solutions of HT in H_2 and DT in D_2. The purpose of these experiments was to look for a difference in vapor pressure of HT and D_2 and to obtain as much data as possible on phase equilibria involving the isotopes of hydrogen. The use of Henry's law constants for the evaluation of liquid partition functions awaited the development of a theory of nonideal isotopic mixtures. A rigorous thermodynamic treatment of such solutions has now been carried through starting from the basic assumption of Prigogine, Bingen, and Bellemans that the excess free energy of mixing arises from the difference in molal volumes of the pure isotopes. The most important contribution was shown to arise from the gas imperfection, and a significant term comes from the fact that the partition function is related to the Helmholtz free energy while the Gibbs function determines the state of equilibrium. The theory gives a good description of solutions of the neon isotopes as well as other properties of solutions of hydrogen isotopes.

The experimental data on HT-H_2 solutions displayed in Figure 14 show conclusively that HT is 22 to 24% more volatile than D_2 over the temperature range 14° to 30°K. The difference arises from a coupling in the liquid between translation and rotation. Theoretical calculations of the effect were carried out starting from the ground state approximation and making an approximate correction for the Boltzmann excitation of the phonons. The results showed that such an approximation is adequate for the study and in fact cast doubt upon all studies on quantum effects in liquid hydrogen which start with the first quantum

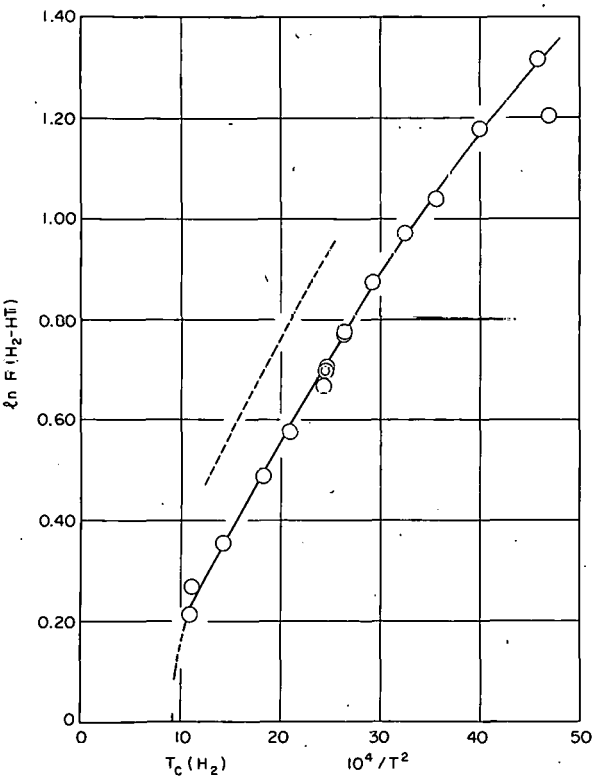


Figure 14. Henry's law constants for dilute solutions of HT in liquid hydrogen. The dashed curve is for a similar solution of D_2 in liquid hydrogen.

correction. Calculations of the shift in ground state energy by perturbation theory were carried out for rough models of the liquid. First-order perturbation theory gives a value of the coupling parameter twice the experimental value. Extension to second order by Bellemans and Friedmann gives remarkable agreement between the calculated and experimental coupling parameters.

Isotope Effect on Molal Volume

A correlation of the molal volumes of the isotopic liquid hydrogens with their zero-point energies was carried out through the use of a Grüneisen-type equation of state. Within the assumption of an isotope independent compressibility, the value of the Grüneisen constant derived from isotopic molal volumes is in reasonable agreement with that from thermal measurements and the equation of state of liquid D_2.

Chemical Identity of the Proton in Aqueous Solution

The equilibrium constant for the fractionation of deuterium between water and the solvated proton, i.e., for the reaction

$$H_2O+D^+(H_2O)_n=HDO+H^+(H_2O)_n$$

has been measured in two different ways. The first depends upon the fact that the proton magnetic resonance frequency for a mixture of two species in rapid equilibrium is a concentration-weighted mean of the frequencies of the individual species. In this way, the concentration of H^+ in acid solutions in H_2O and H_2O-D_2O mixtures can be determined, with subsequent evaluation of the equilibrium constant for the above reaction. The second method is based on the mass spectrometric measurement of the D/H ratio in acid solutions compared with the ratio in the equilibrated vapor phase. This information, combined with analogous data for pure water, also leads to a value for the same equilibrium constant. Each of these methods gives an equilibrium constant dependent on q, the number of equivalent protons in a hydronium ion ($q=2n+1$). The values from the two methods are concordant only if n is unity. This provides evidence for the formulation of the hydronium ion in solution as H_3O^+, corresponding to the structure which has been found in certain crystalline acid hydrates. No doubt this ion is further solvated, but the additional water molecules do not contain hydrogen atoms which are equivalent to the proton by the criteria of isotopic fractionation and proton magnetic resonance shifts.

Analogous measurements of the D/H ratio in the vapor above alkali hydroxide solutions have been used to obtain the equilibrium constant for the reaction

$$OD^-+H_2O=OH^-+HDO\,.$$

The combination of this and the equilibrium constant for acid solutions can be related to the ratio of the dissociation constants of light and heavy water. The values are in good agreement.

Energy Surfaces for Atom-Molecule Reactions

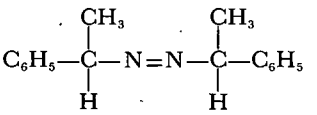
Kinetic isotope effects in the reaction of bromine atoms with H_2-HD, H_2-HT, and H_2-D_2 mixtures have been measured over the temperature range 175° to 350°C. The rate constant ratios thus obtained are very similar to those found in the reaction of chlorine atoms with the same hydrogen isotopes. (Because of the difference in the temperatures at which measurements can be made, the chlorine atom data are extrapolated from lower temperatures.) This observation contradicts certain previously made generalizations relating the isotope effect to bond strengths or activation energies, since these quantities are quite different in the two systems.

The experimental results are compared in Figure 15 with certain models for the activated complex, with not very good agreement. However, an *ad hoc* fit of the data by adjustment of the vibrational frequencies of a linear transition state leads to agreement within $<10\%$ for all three isotopic species. Figure 16 shows the fits obtained with a repulsive H-H force (set *A*), with a repulsive H-Br force (set *B*), and with a 1-3, 2-3 force concomitant with a zero value for the 1-2 force (set *C*).

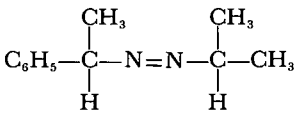
Concerted Versus Two-Step Reactions

Isotope effect studies in the decomposition of dialkyl azo compounds have been continued. A new azo compound together with its deuterated isomers was synthesized. In previous work, the magnitude of the secondary α-deuterium isotope effect indicated that azobis-α-phenylethane (I) decomposed thermally with both C—N bonds rupturing in a concerted manner. The same was true for α-phenylethylazo-2-propane (II) except that the secondary effect indicated that the benzylic carbon-nitrogen bond is stretched more than the

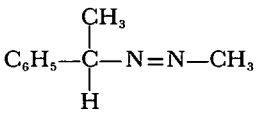
2-propyl carbon-nitrogen bond at the transition state. This correlates well with the resonance energies of the incipient radicals. A more unsymmetrical mechanism might be obtained when the two different groups on either side of the azo linkage show a greater difference in resonance energies than in cases (I) and (II). This was realized with compound (III). α-Phenyl-α-*d*-azomethane shows an effect of $k_H/k_D = 1.13 \pm 0.01$ while α-phenyl-α-*d*-azomethane-d_3 gives an effect $k_H/k_D = 0.97 \pm 0.01$ at 160°C. This indicates that the benzylic carbon-nitrogen bond is breaking but the methyl nitrogen bond is not; in fact there may even be some tightening during this process. To check the latter effect the C^{13}-effect was studied for α-phenylethylazomethane-C^{13} (natural abundance) by burning the methane produced and analyzing the CO_2.



(I)



(II)



(III)

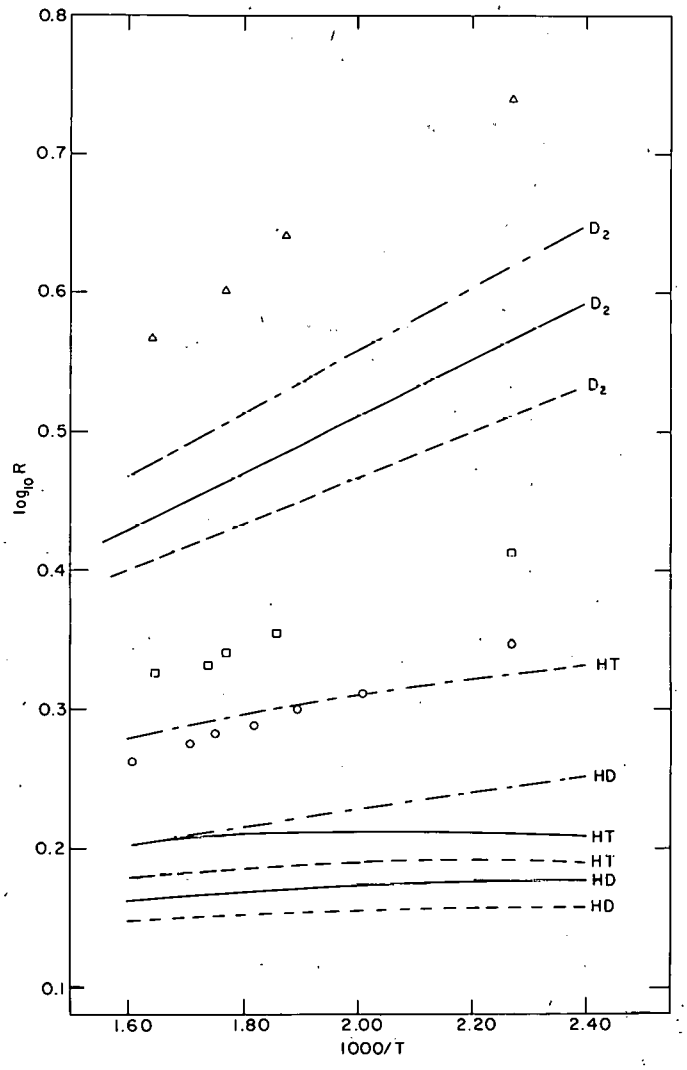


Figure 15. Comparison of theoretical and experimental values of log R (ratio of isotopic rate constants compared to H_2) for bromine atom reactions with the isotopic H_2 molecules. — WTE potential; – – – Sato potential; - - - BEBO of Johnston and Parr.

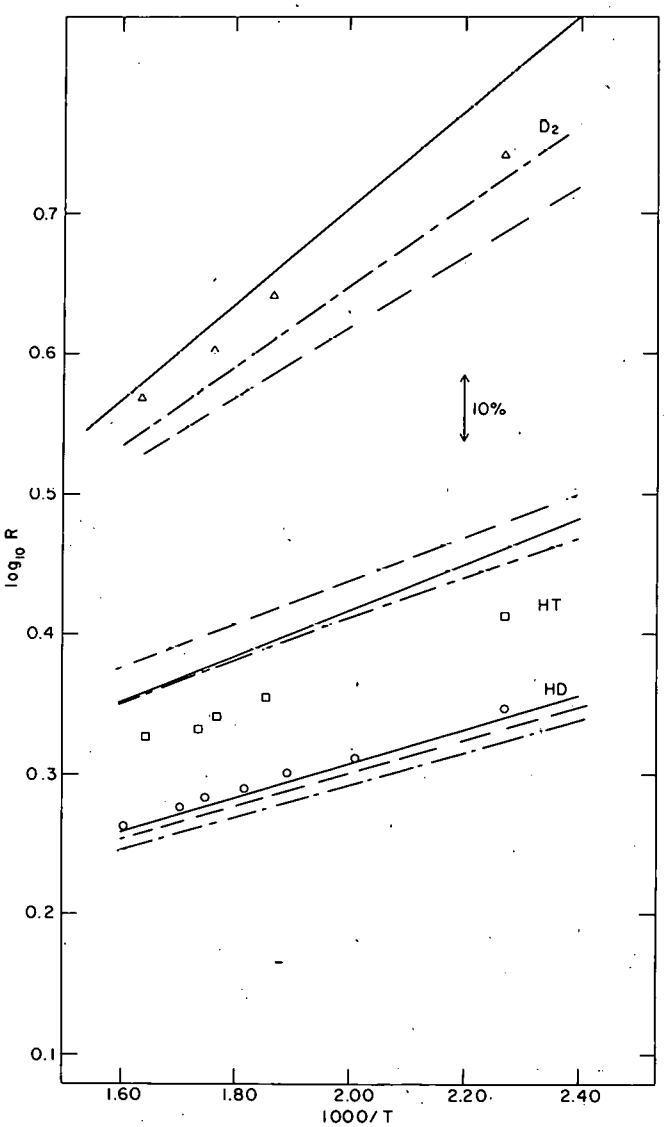
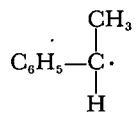


Figure 16. Comparison of experimental values of log R with theoretical ones calculated from *ad hoc* force fields. — Set A; - - - set B; – – – set C.

The effect, $k_{12}/k_{13} = 1.0068 \pm 0.0007$, is very small and less than that calculated on the assumption that the $CH_3N_2\cdot$ moves away from the

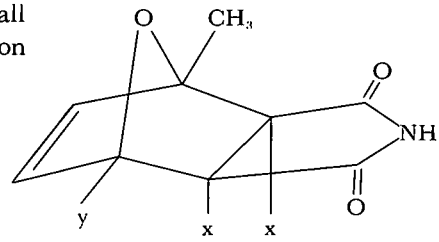


group ($\nu_{1L}^{\ddagger}/\nu_{2L}^{\ddagger} = 1.0082$). Again, the fact that the measured effect is less than the calculated may mean that there is some C—N bond tightening in the methyl azo group at the transition state. The isotope effects, therefore, indicate the transitory existence of the $CH_3N_2\cdot$ radical. The rate constant for the decomposition of $CH_3N_2\cdot$ can be set at about 10^{11} sec^{-1}. The entropy of activation has also been measured.

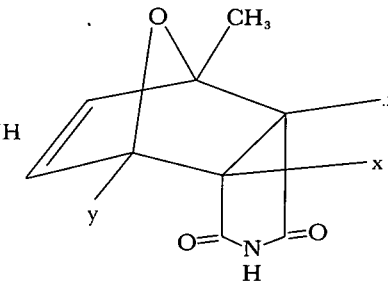
Another case of methyl radical production has been studied: the thermal decomposition of the cumyloxy radical. The decomposition was studied over the temperature range $-9°$ to 75°C. One of the methyl groups in the cumyloxy radical was fully deuterated [ϕ—$C(CH_3)(CD_3)O\cdot$] while the other equivalent one was protonated. The secondary isotope effect was studied as an intramolecular competition. The results for the secondary isotope effect can be represented in an Arrhenius form with a pre-exponential of 0.93 and an activation energy difference of 1170°K. From the rule of the mean this corresponds to a secondary isotope effect per H atom in α C—C bond rupture of 1.17 at $-9°$ (and 1.12 at 75°C). The values of the "pre-exponential" factor and the activation energy difference are consistent with a model of the transition state in which the methyl radical is rather detached from the molecular skeleton. Szwarc has found a similar result for the analogous inverse reaction in studies of the addition of methyl radicals to styrene. The studies serve to substantiate the method of secondary α-deuterium isotope effects as a tool for the differentiation between concerted and two-step mechanisms.

Mechanism of Diels-Alder Reaction

The study of the mechanism of the Diels-Alder reaction has been continued with the use of secondary effects. Both *exo* (IV) and *endo* (V) adducts of malenide and 2-methylfuran have been prepared with (*a*) x = y = H; (*b*) x = D, y = H; and (*c*) x = H, y = D.



(IV)



(V)

The results at 85°C show that for the *exo* adduct $k_H/k_D = 1.13$ (case *b*) and $k_H/k_D = 1.07$ (case *c*). These results parallel those obtained for the *exo* adduct from 2-methylfuran and maleic anhydride and probably represents a case of concerted two-bond rupture. The isotope effect for the *endo* compound (65°C) is $k_H/k_D = 1.15$ (case *b*); the effect for case *c* is not known with certainty as yet. Activation parameters are being measured and will be compared with the isotope effects.

PHYSICAL CHEMISTRY

Kinetics of Electron Transfer Reactions

The rate laws for a large number of rapid oxidation-reduction reactions were determined with fast-flow and temperature-jump techniques. Oxidants employed included cerium(IV), manganese(III), cobalt(III), and iron(III). Reductants included iron(II), a series of substituted phenanthroline complexes of iron(II), dipyridyl and mixed dipyridyl-cyanide complexes of iron(II), and chromium(II). Reactions involving cyanide complexes of molybdenum, tungsten, and iron were also investigated. The results afford extensive confirmation of the linear free energy relationships predicted by the theory of redox reactions developed by R.A. Marcus. This theory leads to a simple relationship between the specific rate of the net reaction and the specific rates of the corresponding electron exchange reactions, when the mechanisms are all of the outer-sphere type. A comparison of experimentally determined rate constants with those so predicted is given in Table 4. The agreement is gratifying in most cases. Large deviations may indicate complex reaction mechanisms, a point worth further study. In one reaction of interest, the manganese(II)-manganese(III) electron exchange, the specific rate predicted from data on several cross reactions is quite slow; attempts to

Table 4

Comparison of Observed and Calculated Rate Constants in 0.5 *M* Sulfuric Acid at 25.0°

Reaction	k_{12}, mole^{-1} sec^{-1}	
	Observed	Calculated
Ce(IV)-$W(CN)_8^{4-}$	$>10^8$	6.1×10^8
Ce(IV)-$Fe(CN)_6^{4-}$	1.9×10^6	6.0×10^6
Ce(IV)-$Mo(CN)_8^{4-}$	1.4×10^7	1.3×10^7
$IrCl_6^{2-}$-$W(CN)_8^{4-}$	6.1×10^7	8.1×10^7
$IrCl_6^{2-}$-$Fe(CN)_6^{4-}$	3.8×10^5	5.7×10^5
$IrCl_6^{2-}$-$Mo(Cn)_8^{4-}$	1.9×10^6	1.0×10^6
$Mo(CN)_8^{3-}$-$W(CN)_8^{4-}$	5.0×10^6	1.7×10^7
$Mo(CN)_8^{3-}$-$Fe(CN)_6^{4-}$	3.0×10^4	2.7×10^4
$Fe(CN)_6^{3-}$-$W(CN)_8^{4-}$	4.3×10^4	5.1×10^4

measure it directly have continued to be unsuccessful presumably because of separation induced exchange.

A result of considerable interest was obtained in experiments on the oxidation of iron(II) by cobalt(III) in the presence of chloride. The question involved was whether the electron transfer proceeds by an inner- or outer-sphere mechanism. Definite experimental evidence for inner-sphere mechanisms has hitherto been obtained only in those cases in which the transfer of a bridging group in the activated complex results in a substitution-inert species. By fast-flow methods it has now been demonstrated that the substitution-labile species $FeCl^{2+}$ is the direct product of the oxidation of Fe^{2+} by $CoCl^{2+}$, and that this reaction proceeds via an inner-sphere activated complex in which the chloride is bonded directly to both the cobalt and the iron.

Metal Ion Complexing by Anions

A considerable body of data on the effects of chloride on the thallous-thallic exchange reaction has been obtained in the past but could not be quantitatively interpreted because of the lack of definitive values for the stability constants of the chloro complexes of trivalent thallium. A similar problem arose in connection with recent studies of the oxidation of Cr(II) by Tl(III) in the presence of chloride. Solvent partition equilibria of thallium chlorides have been under investigation with the hope that reliable values of the stability constants of $TlCl_{3(aq)}$ and $TlCl_4^-{}_{(aq)}$ could be obtained by this method.

Table 5

Stability Constants of $TlCl_3$ and $TlCl_4^-$ Estimated From Solvent Extraction Data
[Ionic strength 0.50 *M*, $(H^+)=0.04$ *M*, chloride range 3.5×10^{-4} to 0.46 *M*, extractant 1% tributyl phosphate in hexane]

T, °C	D_3	K_3	K_4
20	1.51	488	39
25	1.22	484	41
30	0.98	479	43
ΔH (kcal/mole)	−7.6	−0.4	+1.7

NOTES:
1. $D_3=(TlCl_3)_{organic}/(TlCl_3)_{aqueous}$;
   $K_3=(TlCl_3)/(TlCl_2^+)(Cl^-)$ aqueous phase ;
   $K_4=(TlCl_4^-)/(TlCl_3)(Cl^-)$ aqueous phase.
2. In the analysis of the low chloride data a value $K_2=9\times10^4$ was assumed.
3. In the analysis of the high chloride data a value $K_5=(TlCl_5^=)/(TlCl_4^-)=0.4$ was taken for best fit. It is not known whether the pentachloro species exists in solution, or whether the effect so fitted is an activity coefficient change due to change of medium.

It has been found that diisopropyl ether extracts both $TlCl_3$ and $HTlCl_4$, and that the extraction equilibria are complicated by both dissociation and polymerization phenomena in the organic phase. On the other hand, conditions have been found under which tributyl phosphate–hexane mixtures appear to extract only $TlCl_3$. Estimates of the stability constants of $TlCl_{3(aq)}$ and $TlCl_4^-{}_{(aq)}$ at various temperatures were obtained from systematic extraction measurements with TBP-hexane mixtures and are given in Table 5. An estimate of the hydrolysis constant of $TlCl^{2+}$ has also been obtained. There is gratifying, although not yet complete, agreement with results recently obtained by different methods in other laboratories.

The extraction of methylene blue perchlorate into 1,2-dichloroethane is also under study. This provides one of the most convenient methods for the analytical determination of trace amounts of perchlorate in aqueous solution. The physical chemistry of this system is being investigated. Extraction quotients and the absorption spectra of both phases have been determined over a wide range of conditions. Some unanswered questions remain as to the state of aggregation of the material in each phase.

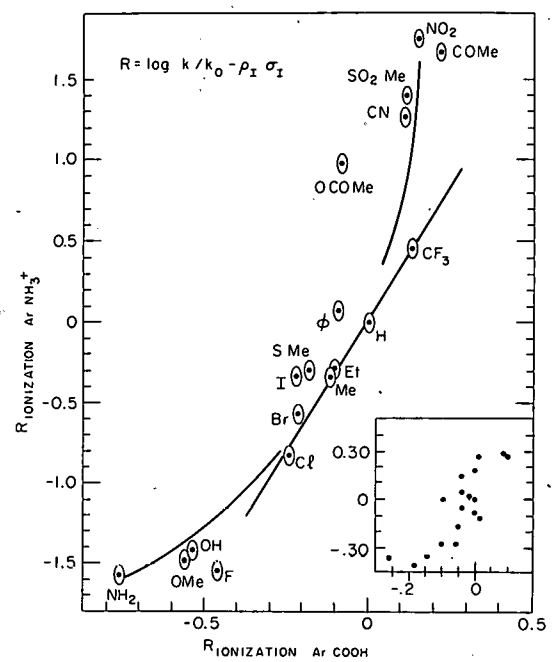


Figure 17. Taft's resonance terms, R, for the ionizations of *para*-substituted analinium ions plotted against those for the ionizations of *para*-substituted benzoic acids. Inset: the same plot to the same scale for *meta*-substituted cases.

Complex equilibria involving Hg(II), Cl^-, and SCN^- have been investigated spectrophotometrically. The results obtained to date do not agree with conclusions in the literature, and it appears that $Hg(SCN)_2$ may be polymerized in aqueous solution. Conductance measurements indicate that the aggregates are uncharged.

Linear Free Energy Relationships

Substituent effects on the reactivities of organic systems are being investigated by the linear free energy relationships of the Hammett-Taft type as well as by semiempirical quantum mechanical calculations by the LCAO*-MO method. Attempts are being made to interrelate the two approaches with the hope of providing quantum mechanical bases for the linear free energy relations.

Empirical refitting of the Taft parameters has been carried out with special emphasis on the σ^0 reactivities. These apply to reactions in which resonance is precluded between the substituent and the reaction center. These reactions provide a good basis from which to construct a set of linear free energy parameters. In particular, it has been found that *meta* inductive effects are, in fact, proportional *but not equal* to the *para* effects. These have formerly been explicitly assumed to be equal to one another. The implications of this result to the problem of separation of resonance and inductive effects is under investigation. The calculations show that inductive effects are transferable, after scaling, from aliphatic to aromatic systems in the absence of resonance contributions. A quantum mechanical calculation employing the Hückel method up to second-order perturbations has been carried out for aromatic systems with both conjugative and nonconjugative substituents. These lead to linear free energy equations for reactivities in which the substituent and reaction center effects are separable. In agreement with experiment it is found that a plot of log k/k_0 versus σ plots, as shown in Figure 17, shows a nonlinear relationship. The condition that resonance and inductive effects be proportional to one another has been established theoretically. The ratio of *para* to *meta* inductive parameters has been calculated by the above quantum method to be 0.8 as compared with the value 0.85 to 0.90 derived by the statistical analyses of the available pertinent data.

*Linear combination of atomic orbitals.

Hyperconjugation in Carbonium Ions

The hydrolysis of olefins and the dehydration of alcohols have been selected as prototype reactions involving carbonium ions. Electronic energies have been calculated by the Wheland-Mulliken MO method with self-consistent charge redistribution. Hyperconjugation gives significant stabilization to carbonium ions derived from alkyl substituted olefins by proton addition. These results show that hyperconjugation alone suffices to explain the Baker-Nathan effect, and the Markownikoff and Saytzeff-Wagner addition rules. Contrary to experimental indication, these theoretical calculations predict relative C—H to C—C hyperconjugative effects to be the same in olefinic and aromatic systems undergoing similar reactions.

The relative rates of anti- to direct Markownikoff addition have been studied experimentally to test the theoretical prediction of substantial hyperconjugation. The system investigated was protium-deuterium exchange of the secondary hydrogen of isopropanol in D_2O-D_2SO_4 media. The ratio k_{anti}/k_{normal} was found to be $<4\times10^{-4}$ at 60°C. This is in agreement with the predictions of hyperconjugative stabilization of the carbonium ion but

does not rule out some stabilization from inductive effects. Isotopic effects in the interconversion rates have also been determined and support the hypothesis that the transition state or states resemble hydrated classical carbonium ions.

Molecular Excitation by Electron Impact

Theoretical calculations have been continued on excitation and de-excitation of molecular vibration by slow electron impact. A mechanism has been proposed which involves compound negative ion states as intermediates. Numerical calculations have been carried out for the nitrogen molecule. The multipeak structure observed in experimental excitation functions has been accounted for. Figure 18 shows the agreement between calculations of the total cross section for vibrational excitation of ground state N_2 and experiment.

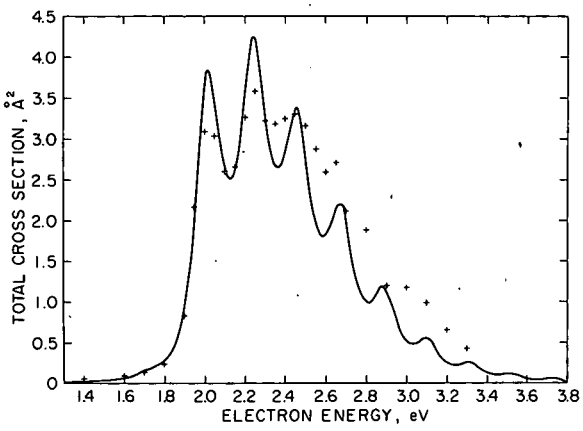


Figure 18. A comparison of the experimental and theoretical total excitation functions for vibrational excitation of the ground N_2 molecule. The continuous curves are the present calculation and the crosses are obtained by summing up the normalized experimental data measured at an angle of 72°.

Hypervirial Theorem

A unitary operator formalism has been investigated which allows generation of a general eigenfunction from a knowledge of the function for one value of a parameter. This operator formally allows generation of a diatomic wave function at any internuclear distance, R, from a knowledge of the wave function when the atoms are an infinite distance apart. The properties and significance of superoperators have been discussed. The diagonal matrix elements of the equation of motion are constant in time (hypervirial theorem). The off-diagonal elements of the hypervirial operator oscillate in time with frequencies related to the energy differences between the corresponding stationary states of the system.

The off-diagonal hypervirial theorem is as powerful as the hypervirial theorem for dealing with many quantum mechanical problems. The off-diagonal theorem is useful in the construction and improvement of wave functions. As a special example, the restricted fourth alternative expression for the dipole transition matrix elements has been derived between states with nonzero orbital angular momenta in hydrogen-like atoms. A scheme has been evolved for improving wave functions of excited states. Finally, the theorem has been used to relate statistical fluctuations to the uncertainty principle.

Ion-Molecule Reactions

During the past year the following ion-molecule reactions have been studied:

$$HD^+ + He \rightarrow HeH^+ + D$$
$$\rightarrow HeD^+ + H$$

$$HD^+ + Ne \rightarrow NeH^+ + D$$
$$\rightarrow NeD^+ + H$$

$$Ar^+ + HD \rightarrow ArH^+ + D$$
$$\rightarrow ArD^+ + H$$

$$Kr^+ + HD \rightarrow KrH^+ + D$$
$$\rightarrow KrD^+ + H$$

Mixtures of HD and rare gas molecules were subjected to ionization by electron impact, and the yields of the reactions listed above were determined as a function of reactant ion kinetic energy. In all cases isotope effects were observed which varied with reactant kinetic energy. For reactant ion kinetic energy <1 eV, the ratio of rare gas hydride to deuteride was <1 and increased with increasing ion kinetic energy. Above 1 eV a gradual increase continued in the Ar^+ and Kr^+ reactions. For reactions of HD^+ with He or Ne the ratios HeH^+/HeD^+ and NeH^+/NeD^+ increased with reactant ion kinetic energy up to 2 to 3 eV and then decreased. These results are not easily explained by one simple reaction mechanism. The difference in behavior between reactions of HD^+ and He or Ne and rare gas ions and HD neutral species is correlated with the observation of an apparent decrease in reaction rate with increasing

Table 6

Calculated Stabilities of Rare Gas Hydride Ions

Ion	Equilibrium internuclear distance, r_e, Å	Force constant, K, dynes/cm	Dissociation energy, D_0, eV	
			Calculated	Exptl. limits
NeH^+	0.81	5.52×10^5	(2.15)	2.15
ArH^+	1.14	5.53×10^5	3.03	2.1 –
KrH^+	1.27	5.66×10^5	3.46	3.4 – 4.09
XeH^+	1.46	3.79×10^5	2.66	1.20 – 3.19

ion kinetic energy in the H_2^+-He and H_2^+-Ne ion-molecule reactions. The effect had hitherto been ascribed to a decrease in collision efficiency for high velocity reactant ions. It is now concluded to result from a loss of product by decomposition of excited molecule ions produced in the reaction. The excitation energy comes in part from the internal energy in the reaction. Similar energy transfer is not effective in dissociating the products of the Ar^+ and Kr^+-HD reactions because the internal energy available in HD molecules is considerably less than in some of the HD^+ ions produced by electron impact. This component of product excitation is lacking.

The lower ion kinetic energy reactions in all four HD–rare gas systems provide evidence of energy transfer processes which, when considered in the light of previous work, indicate energy transfer subsequent to the initial reactive collision rather than energy transfer simultaneous with that collision. It is concluded that a special threshold concentration of internal energy is required to initiate the reaction, but after the process has begun there are mechanisms which permit the flow of a small fraction of the reactant kinetic energy into internal degrees of freedom of intermediate complexes and the final reaction product.

Force Fields for Rare Gas Hydrides and Hydride Ions

Analysis of the results of rare gas–HD ion-molecule reactions has been aided by a theoretical investigation of the properties of the rare gas–hydride diatomic molecules and molecule ions. An electrostatic model proposed originally by Platt has been used to estimate internuclear distances and force constants for the XH^+ and XH species (where X refers to He, Ne, Ar, Kr, and Xe). These data were then used semiempirically to obtain a set of dissociation energies for the respective diatomic species. The results are given in Table 6. Calculations on neutral XH molecules indicated extremely weak bonding with dissociation energies so low that observation of these species under ordinary conditions of temperature and pressure is considered very improbable.

Enzymatic Reactions Below 0°C in Methanol-Water Solvents

The present research on complete enzymatic reactions below 0°C may be regarded as the first stage in the study of the intermediate reactions at low temperatures. The course of the enzymatic rates was followed by fluorometry. Mixtures of water and methanol in high concentrations served as solvents. Buffered 42 vol % methanol at room temperature produced irreversible and reversible denaturation of α-chymotrypsin and lactic acid dehydrogenase. These processes in the two enzyme systems proceeded differently with change in temperature. Incubation experiments of solutions prepared at +15°C showed that α-chymotrypsin in buffered 40, 50, and 60% methanol lost no perceptible activity over time intervals long compared with those needed for measurement of initial rates. Solutions prepared below +10°C had kinetic properties reversible with temperature. At 0°C, their rates were found linear with enzyme concentration, and with that of the substrate, N-acetyl-L-tryptophan ethyl ester, in the range of low concentrations. Activation energies of the enzymatic rates in 40, 50, and 60% methanolic solutions were practically equal between +10°C and −10°C. α-Chymotrypsin exhibited sufficient catalytic activity at −33°C in 50% methanol to furnish a definite rate within $<$1 hr and in 80% methanol within $<$1 day.

Nuclear Engineering

In January 1964 Dr. Herbert J.C. Kouts, Associate Head for Experimental Physics of the Nuclear Engineering Department's Reactor Physics Division, became chairman of the AEC's Advisory Committee on Reactor Safeguards. The 31st Brookhaven Lecture, *The Nuclear Reactor Comes of Age*, was presented in November 1963 by Mr. Jack Chernick, Associate Head for Theoretical Physics of the same Division. Dr. Robert L. Hellens, leader of the Reactor Physics Analytical Group in this Division, will be working for a year in England at Winfrith Heath on the physics of fast reactors. Nine papers for the Third United Nations International Conference on the Peaceful Uses of Atomic Energy, to be held in August and September 1964 at Geneva, Switzerland, were authored or co-authored by members of the Nuclear Engineering Department.

Basic research is the first and largest, in terms of man-years of effort, of three categories that describe the current program of the Department. This research encompasses fundamental studies in reactor physics, chemistry, and metallurgy. Studies are also carried out in the fields of reactor materials at high temperatures, liquid-metal heat transfer and containment, and the direct conversion of heat into electricity.

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

The engineering and evaluation studies in the third category are focused on practical application of the work in the preceding categories. Typical studies that continued during the year concerned settled bed, chemonuclear, and rotating bed reactor concepts. Assistance was given to the Division of Reactor Development of the AEC in the evaluation of military reactor and nuclear safety programs.

Construction of the High Flux Beam Research reactor (HFBR) was essentially complete at the end of June 1964, and control of the facility was taken over by the BNL Reactor Division. A safety analysis report has been transmitted to the AEC with a request for approval to operate the facility. Hearings before the Advisory Committee on Reactor Safeguards are tentatively scheduled for July 1964. In the first several months of fiscal 1965 the HFBR will undergo preoperational tests with light water and dummy fuel elements. After the system has been drained, dried, and filled with heavy water, a conventional loading to criticality will be carried out.

Design was completed and construction commenced on a 100-kW source reactor in the Critical Assembly Area. This reactor will be used to irradiate small miniature lattice assemblies and also plutonium exponential assemblies for experiments in basic reactor physics.

A dry box was set up in the Critical Assembly Area to handle radioactive materials in conjunction with the $U^{233}O_2$-ThO_2 lattice experiments. This box was used for some plutonium experiments several years ago and is adequate to contain the alpha contamination of either plutonium or U^{233}.

An addition to the Metallurgy Division Building was started, and an alpha facility for handling radioactive plutonium fuel materials was designed and construction begun.

A neutron generator to be used for research on fast neutron reactions was set up in a specially built shielded room in the Hot Laboratory (see Figure 1).

The *High-Temperature Liquid-Metal Technology Review*, a bimonthly review of current research and development in the high-temperature liquid-metal field in the U.S., is now in its second year of publication by the Department's Chemistry and Chemical Engineering Division and has proved very popular as a reference source for workers in this fast-growing field.

Work in the area of liquid-metal heat transfer has involved completion of design of a boiling potassium heat transfer loop, a cross-flow rod bundle for a NaK heat transfer loop, and a new eccentric annulus test section for a mercury heat transfer

loop. A pumped boiling sodium loop has been designed and is now being fabricated.

Investigations are in progress on a high flux reactor to accommodate large in-pile loop and capsule experiments. The possibility of modifying the Brookhaven Graphite Research Reactor (BGRR) for an increased neutron flux is being studied.

The installation in the BGRR of an air-cooled capsule irradiation facility was completed this year. The facility is required for testing settled bed reactor fuels in a NaK fluid environment at 760°C (1400°F). Tests of the facility were completed and two capsule irradiations were made. A continuing effort is required to improve present capsule designs and to design and build capsules for irradiation at the Engineering Test Reactor (ETR).

A conceptual report is being prepared for a 1000-MW(e) settled bed reactor. Both an axial and a radial flow core will be discussed, with the reference design and plant layout made for the axial flow core.

Effort on the chemonuclear in-pile loop increased this year. This facility will be used for studies of gas-phase chemical reactions using fission fragments as an energy source. The design of the in-pile section was completed. All major components of the loop have been ordered or designed.

This year the High Intensity Radiation Development Laboratory (HIRDL) went into full operation. Approximately 1,375,000 curies of Co^{60} were received and handled. Cs^{137} in the amount of 217,000 curies has been received from the Savannah River plant and is being processed.

Personnel from the Nuclear Engineering Department, and also from the Biology, Medical, and Physics Departments and the Information Division, operated gamma facilities and presented lectures at exhibits in Bogotá, Colombia, and Belgrade, Yugoslavia, sponsored by the US AEC Division of Special Projects.

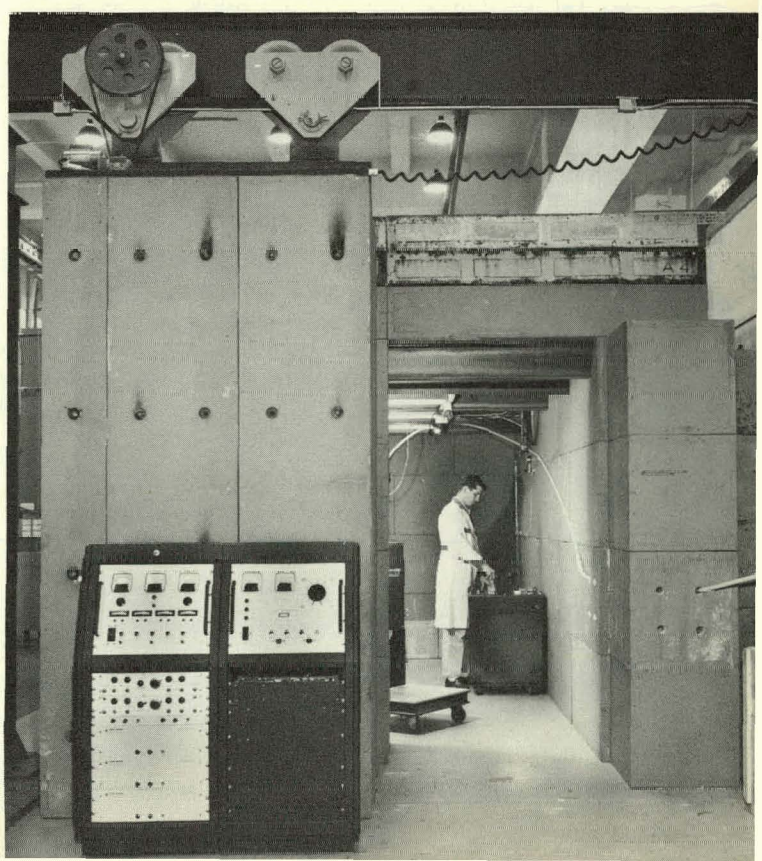
REACTOR PHYSICS

Theoretical Reactor Physics

Research in the Reactor Physics Theoretical Group has been devoted to problems in multivelocity transport theory for thermal neutrons, reactor kinetics, fluid flow, and general reactor studies. Research in thermal neutron transport theory has included (1) use of the WKB method to compute infinite medium spectra, (2) study of the time eigenvalues and diffusion lengths of various moderators, and (3) direct numerical simulation of the approach to equilibrium of a pulsed system. Studies in reactor kinetics include a definitive investigation of the 2-temperature feedback problem. General studies of 2-phase flow and fluid flow past a line of spheres have been started. General reactor studies included work on Pu-fueled reactors with high conversion ratios and calculations in support of the HFBR project.

Several papers were published on aspects of the Milne problem in order to determine angular distributions of neutrons and extrapolation distances at a vacuum boundary. A series of calculations of diffusion parameters of graphite was carried out in support of an experiment performed at BNL. An invited review paper on practical methods for computing thermal neutron spectra was presented at the June 1963 meeting of the American Nuclear Society. A review paper on the resonance absorption of neutrons was prepared for the third Geneva Conference, and the theoretical group participated in the preparation of a second paper on neutron thermalization. Papers comparing theory with experiment were completed on tempera-

Figure 1. Neutron generator being set up in the Hot Laboratory for research on fast neutron reactions. The pneumatic tube penetrating the shield (right) is used for carrying samples.



ture coefficients in graphite reactor lattices and on TREAT transients. It was determined that the slowing-down time in hydrogen depends very little on the neutron scattering model but is strongly dependent on absorption rates.

The hydrodynamic equations for 2-phase flow have been studied. A new relationship between void volume and quality and a simple (steady-state) slip ratio correlation was developed. Good agreement was obtained with transfer function data generated by the Space Technology Laboratory. Solutions have been obtained for potential flow past a line of spheres, and viscous effects are under investigation. Reactor stability studies were completed on the 2-temperature feedback problem. It was shown that discrepancies in earlier studies were due to the existence of solutions of finite escape time.

Experimental Reactor Physics

Several problems related to research reactor development were investigated during the year. Work continued on neutron physics experiments in direct support of the HFBR. Experiments on near homogeneous U^{235}-graphite assemblies at the minimum reflection critical facility and a series of experiments utilizing $U^{233}O_2$-ThO_2 fuel rods in water lattices were initiated.

Papers on the uses and potentialities of research reactors and on the HFBR were prepared for presentation at the third Geneva Conference.

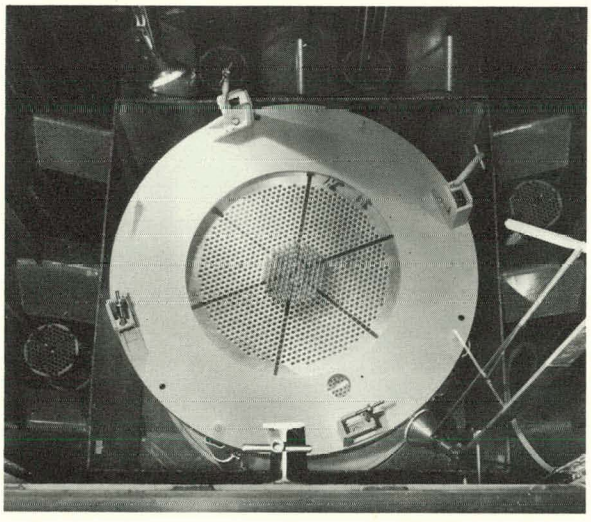
The critical experiments in support of the HFBR included power mapping of a fresh core and also of a core poisoned to simulate burnup conditions. The minimum reflection critical experiments included measurements on three different assemblies of (1) critical mass and buckling, (2) the thermal neutron disadvantage factor, (3) the room return of neutrons and its effect on reactivity, (4) the effect of control rods, (5) temperature coefficients, (6) prompt neutron generation time (by pulsed neutron techniques), and (7) spectral indices. Measurements on slightly enriched U lattices were carried out primarily for improvements in experimental techniques. Considerable improvement was obtained in the measurement of thermal neutron disadvantage factors of water lattices and the resonance absorption in U^{238}.

Nine hundred full-length fuel elements and 200 shorter elements (for use in measuring microscopic parameters) were received from Oak Ridge National Laboratory (ORNL). The fuel, composed of particles of $U^{233}O_2$ dissolved in ThO_2 that had been prepared by the sol-gel process at ORNL, was vibration-compacted in 0.500-in.-o.d. Zircaloy tubes. The length of time that fuel can be handled directly is severely limited by the buildup of gamma activity from daughter products of U^{232} present; for the same reason the amount of fuel that can be handled is limited. A view of the water-filled tank used both for critical experiments and for fuel storage is shown in Figure 2. Handling tools for the fuel were designed and constructed. Remotely operated television cameras and a crane were installed. A series of safety experiments was conducted to establish the nuclear and radiation safety of the new facility, and a second series of experiments was completed to establish safe exponential loadings for each water-to-fuel volume ratio. Buckling and reflector savings were measured for seven different lattices, and preparations were begun for measurements in poisoned moderator lattices.

The construction of Neutron Source Reactor II to be located in the Critical Facilities Area was begun. The reactor, which is basically similar to the Neutron Source Reactor (NSR), will be used as a source of neutrons for basic reactor physics studies of water-moderated lattices and related systems.

Cold neutron production experiments have been carried out by use of cryostats in a D_2O thermal column in the NSR. Methyl methacrylate was found to be comparable to methane or parahydrogen in its ability to moderate neutrons in the inelastic scattering region. A critical assembly has been built for use in improving pool reactor neutron beams.

Figure 2. Water-filled exponential facilities and fuel storage facilities for U^{233}-ThO_2 fuel rods



Reactor Physics Analysis

Research in the Reactor Physics Analysis Group has proceeded along three lines. First, existing methods have been used to analyze the exponential experiments done at BNL. These include the U-metal rod and slab lattices, the UO_2 rod lattices, and the Th-U^{233} rod lattices. Second, improvements in the theoretical descriptions are being made: better treatment of the fast effect, consideration of the effect of cladding on resonance capture, and improved treatment of anisotropy in neutron migration. Finally, various experimental procedures for analyzing buckling data (variable loading and flux shape) have been investigated theoretically to uncover possible systematic errors.

The methods developed for the treatment of heterogeneous fast neutron effects have been applied to calculations of first-order changes in fast neutron leakage, fission, and slowing-down in lattices. Comparison with Monte Carlo (MOCA) results shows satisfactory agreement. This code has also been used to determine the anisotropy of the slowing-down moments in uranium oxide water lattices. The effect of cladding on the Dancoff factor for closely packed fuel rods has been investigated by the Monte Carlo method and by an approximate analytical method. Good agreement was found between the two methods.

A theoretical analysis of the uranium oxide exponential experiments at BNL was carried out. When the experimental values of the bucklings obtained by the "flux shape" method were used, the average eigenvalue of the 20 lattices was 0.9918 ± 0.0058. With use of the "variable loading" experimental bucklings, the average value was 0.9953 ± 0.0075. The problem of systematic errors in buckling measurements was discussed at the IAEA Symposium on Exponential and Critical Experiments at Amsterdam (September 1963). An analysis of experimental data on heavy water lattices was completed in cooperation with the Savannah River Laboratory. The analysis of the Th-U^{233} oxide lattices being measured at BNL has been started.

The comparison of theory and experiment for the neutron flux distribution in a lattice cell has shown that the experimental data obtained at BNL and at the Bettis Atomic Power Laboratory are now so accurate that systematic differences of only a few percent in disadvantage factor can be detected. Systematic differences between theory and experiment on the resonance absorption of neutrons in U^{238} rods have been cleared up with improvements in experimental techniques.

The specifications and formats for a punched card system for storing evaluated nuclear data have been developed and reported. This work originated in a series of panel meetings sponsored by the Reactor Mathematics and Computation Division of the American Nuclear Society. Computer programs to process the data are being written at BNL.

Sigma Center

The major effort of the Sigma Center has been directed toward the compilation of neutron cross section data and their evaluation. Work on the second supplement of BNL 325 is under way, and Volumes I and III on the light elements and heavy elements respectively are to be published for presentation at the third Geneva Conference.

A study of the limitations of the optical model for inelastic and differential elastic scattering was carried out by use of the ABACUS-2 program. It was found that the optical model adjusts to good fits of the data for the heavy elements U, Th, Bi, Pb, Au, W, and Ta. A detailed investigation of the statistics of neutron resonance parameters was carried out.

On the theoretical side, *R*-matrix theory was generalized to include the possibility of channel-channel correlations, and several models of the statistical fluctuations of energy levels were investigated. An invited paper on the statistical properties of compound states was presented at the Gatlinburg Conference on Compound Nuclear States (Oct. 10-12, 1963), and a paper on eigenvalue distributions and level densities was read at the Eastern Theoretical Physics Conference at Chapel Hill, N.C. (Oct. 25-26, 1963). The staff of the Sigma Center was instrumental in organizing a symposium on the statistical properties of atomic and nuclear spectra, held at Stony Brook, N.Y. (May 3, 1963). Theoretical investigations of the ground-state energy of the triton and the diffuseness of charge of Li^6 were carried out.

Reactor Evaluation and Advanced Concepts

Settled Bed Reactors. *1. Bed engineering studies.* The feasibility of utilizing *randomly* packed fuel beds in settled bed reactors depends upon the suc-

cess of demonstrating sufficient randomness, reproducibility, and spatial stability of the bed. In accordance with physics calculations, abrupt consolidations of the bed should not be permitted to exceed values equivalent to an arithmetic change of 0.2% in void fraction.

The experimental program throughout the year has been centered on the study of the stability of beds containing ⅛-in. SS spheres, through consolidation by various means, after settling out from a state of fluidization (Figure 3). Two particular accomplishments during the previous fiscal year made it possible to proceed to the study of bed stability with confidence. The first of these was the finding that bed stability is increased substantially by flow-induced drag forces; the second was the development of a simple and direct means for accurately determining the average void fraction of a packed bed. Proceeding from these two findings the stability study involved the progressive consolidation of settled beds by imposed external disturbances and disturbances transmitted to the bed via liquid pulsing. Liquid pulsing by abrupt up-and-down cyclic flow through the bed has proved to be the most satisfactory method and has consistently produced beds which resist further consolidation to the extent that some 4000 blows by a 3-lb hammer were required to bring about 0.2% decreases in void fraction of a 6-in.-diam bed.

An experimental study was begun to investigate an alternative method of bed packing applicable to the Fast Settled Bed Reactor as well as to the fabrication of fuel elements for other reactors. The method is based on the rhombohedral packing of spheres in their most stable configuration to obtain *ordered* packed beds dropped *randomly* into

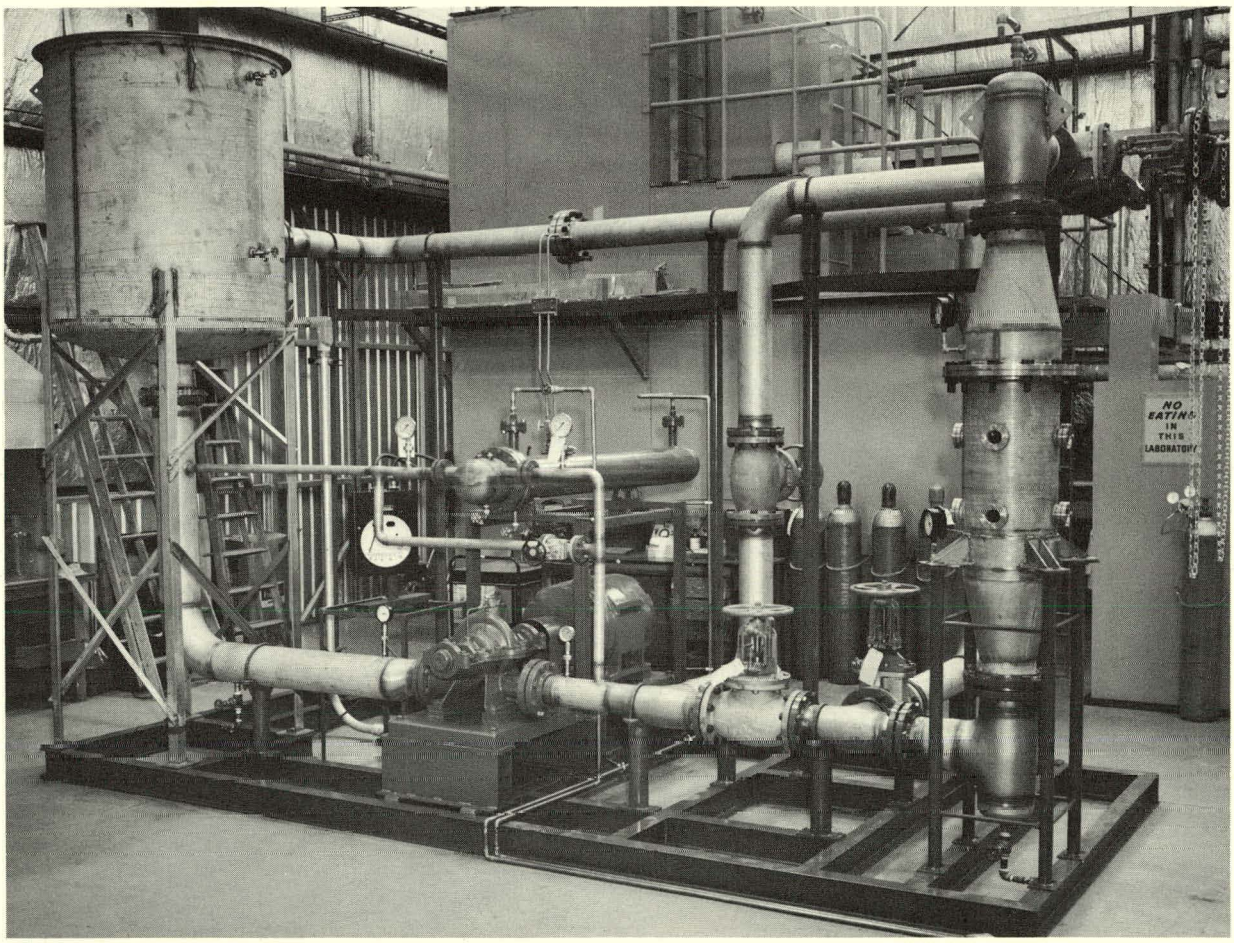


Figure 3. Water test loop (1000-gal/min capacity) with 14-in.-diam bed vessel, designed for scale-up of engineering studies on the settled bed reactor concept.

rigid, square containers. The spheres in any layer form corners of squares, at whose centers cusps are formed into which the spheres in the next layer fall. The bottom layer must be oriented on a base which is either an inverted tetrahedron or a flat plate with suitably spaced countersunk holes. The sides of the square column parallel the *diagonals* of the basic square (Figure 4). By changing the apex angle of the tetrahedron or the hole spacing, the closest center-to-center spacing of spheres in each layer can be varied between 1.00 and 1.23 diameters, and there is a 6% spread in packing density, from 68.05 to 74.05%.

The ordered packed beds exhibit great structural flexibility, and it was found that spheres can move within the bed without disrupting its uniformity. Vertical movement of the bed inside square columns with large height-to-width ratios caused no diminution in bed order. Mixtures of spheres of two sizes varying as much as 5% in diameter, as well as spheres flattened on two opposite sides, could also be packed in ordered beds. This method of containment should make it possible to obtain high bed stability and improved fuel burnup.

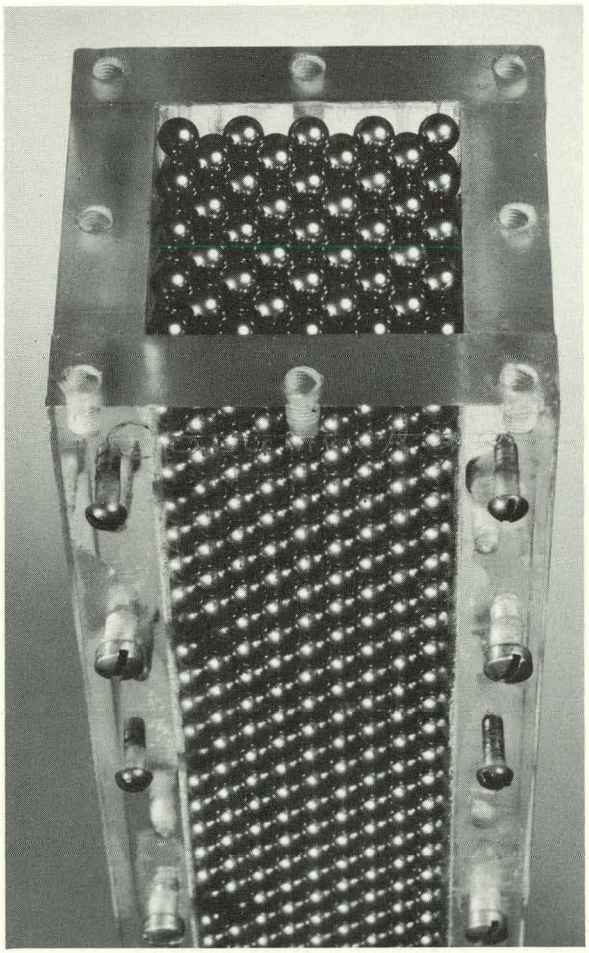


Figure 4. Square Lucite column with ordered packing of ¼-in. stainless steel balls.

2. Fuel development. Enriched cermet fuel pellets of UO_2-SS, UO_2-Fe, and UO_2,-Ni in the range of 80 vol % fuel and 20 vol % matrix have been ordered for irradiation testing. Out-of-pile environmental tests and tests at the BGRR and ETR for low and high burnup screening studies, respectively, will be performed.

The vertical irradiation facility at the BGRR (Figure 5) has been in operation for almost a year. In the first test, 20%-enriched UC spheres were irradiated to a fuel burnup of 0.13% in 1600 hr at 650°C. Postirradiation examination revealed no deleterious effects. A second capsule containing UC and some U-Zr-C spheres is now being irradiated. Preliminary design of an ETR capsule for high burnup irradiation has been completed, and a second vertical hole for an additional in-pile facility at the BGRR has been drilled.

Studies are continuing on the U-Zr-C system. A combination of metallography and lineal analysis, x-ray diffraction, and electron microprobe analysis has been used to establish the phase boundary of the single-phase alloy carbide region at 1600°C. Methods of preparing experimental quantities of spherical carbide pellets are being investigated.

The lattice parameter of ZrC vs temperature was measured to 2200°C. The average volume coefficient of expansion, $a = 1/v(dt/dt)$, derived from these data was 19.3×10^{-6} between 0° and 1000°C and 22.0×10^{-6} between 0° and 2200°C.

3. Physics. Calculations have been carried out for fixing the reference design of the settled bed axial and radial flow reactors. These have entailed studies on fuel loading, breeding rates, and temperature coefficients for possible design configurations. These studies have shown that thin cores must be used in both radial and axial flow reactor types to assure an over-all negative temperature coefficient. Besides providing the negative temperature coefficient, such cores present two additional advantages: (1) increased leakage out of the core shifts more of the breeding to the blanket, and (2) less power is required for pumping through a thin

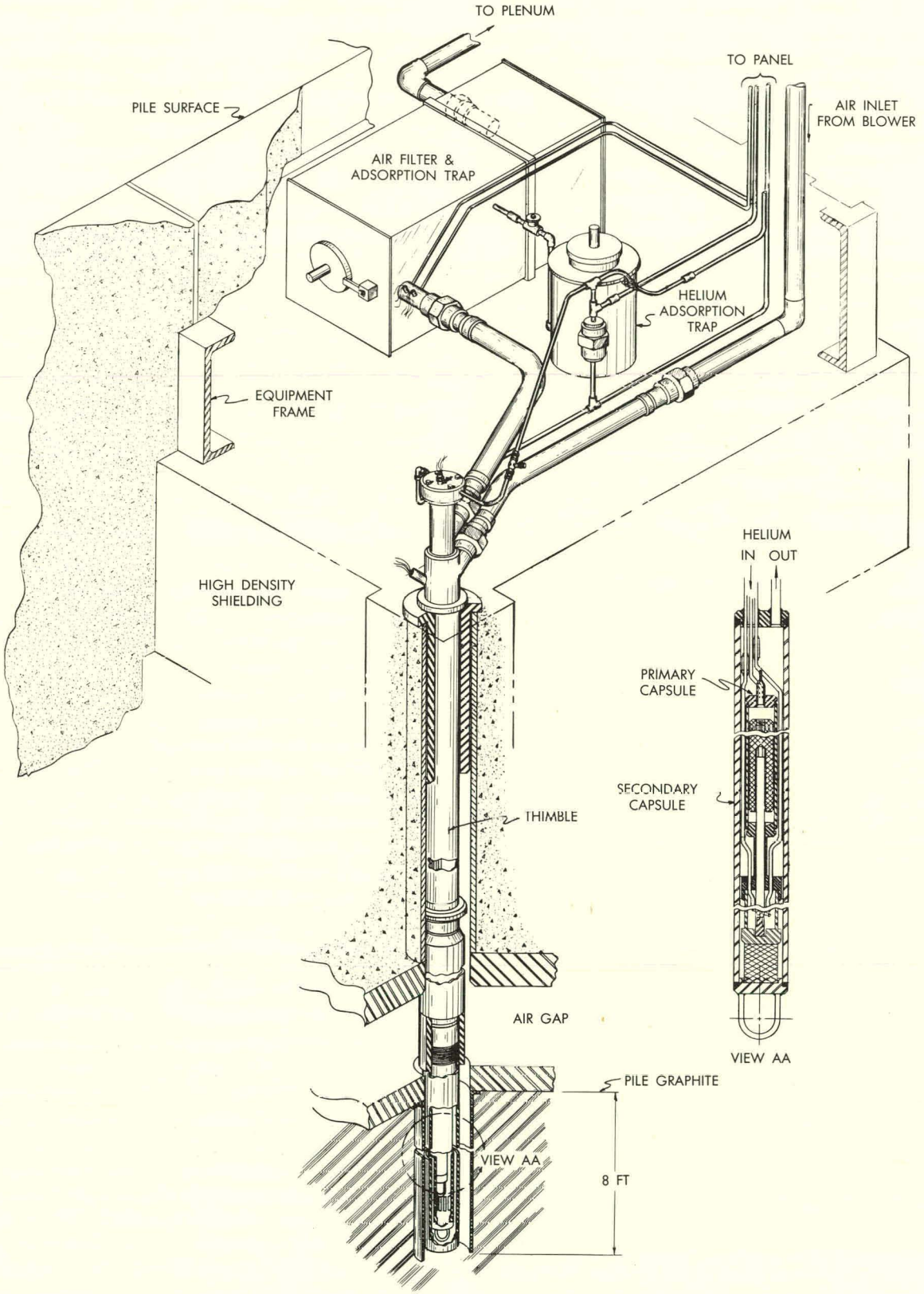


Figure 5. Cutaway diagram of vertical irradiation facility in the Brookhaven Graphite Research Reactor.

wide core. The high breeding rate in these settled bed reactors gives a core breeding rate close to unity and, therefore, a smaller reactivity change with burnup.

The following additional parametric studies were made. (1) Cermets containing 80 vol % fissile and fertile element oxide and 20 vol % matrix material were investigated as substitutes for the reference carbide fuel. (2) The effects of variation of coolant volume fractions between 0.25 and 0.75 were investigated. (3) Calculations were made of the effects of substituting Pb or Bi for the Na coolant, and of the control capabilities of Li as an alloying element in Na.

Other work included the planning of a water-moderated critical experiment for measuring settled bed properties, studies of the kinetics of settled bed reactors, and computer studies of random bed packing.

4. Design study. An extensive study was initiated with the assistance of Burns and Roe, Inc., to investigate the feasibility and design of a 1000-MW(e) fast settled bed reactor. Specific areas of investigation included engineering design, heat transfer and fluid dynamics, reactor physics, fuels, and economics. A similar study will be conducted for a reactor with ordered packing.

Reactor Evaluation. Technical assistance was given to the AEC's Division of Reactor Development in a wide variety of programs, a major part being devoted to program reviews of the Army Reactors Program and the Nuclear Safety Program. Fred Hittman Associates and S.M. Stoller Associates assisted in the respective studies. A number of individual proposals and concepts were submitted by the Division for BNL evaluation, including the Fast Reactor Test Facility (FARET) and studies of fuel management and the chemonuclear production of ozone. Technical assistance was also given to the AEC's New York Operations Office for the 1000-MW(e) pressurized water reactor study.

Chemonuclear Reactors. A study was initiated to determine the characteristics of an $\approx$40-MW(t) reactor to produce 100 tons/day of gas-phase ozone from the direct deposition of fission fragment energy in an O_2 process-coolant stream. The reactor utilizes ultrathin fuel foils and is moderated by external and internal graphite reflectors. It would operate at a temperature near 0°C to minimize ozone product decomposition.

Fuel Cycle Analysis. Work was continued on a general fuel cycle economics code (CYCO) and the THORCYC code for analyzing Th-fueled, fast breeder reactor fuel cycles, both programmed for the IBM 7094 computer. Checkout of THORCYC was completed and the code is now operational.

Direct Conversion. *1. Closed cycle electrochemical converter.* Work was continued on the Pb(l), $PbBr_2$(l), Br_2(g) direct conversion device, and cells can now be constructed having a predictable resistance which does not vary with time. Polarization studies were completed for liquid Pb electrodes in contact with the fused salt, and the specific conductance of the salt was determined over the entire liquid temperature range (373° to 918°C). The duration of corrosion studies has been extended to 1300 hr.

2. Reciprocating liquid-metal piston magnetohydrodynamic generator. Theoretical studies indicated that a very light (0.5 lb/kW), high thermal efficiency (20%), compact (1 kW/cc), high-temperature liquid-metal generator can be made by using a slug of liquid K driven by K vapor (2400°F) in reciprocating motion. It can be coupled to a reactor heat source for space or commercial power.

A small, steady-flow dc generator was tested with Hg over a wide range of velocity, field, and load. Measured efficiency was only 60% because of high hydraulic loss; an efficiency of >90% would have been obtained with K. An improved oscillating-flow ac generator (10 kW) is being constructed.

Slug stability studies with accelerated Hg cylinders in magnetic fields showed that the slug is stable at several hundred g's for a travel length greater than that required for the generator.

METALLURGY

Reactor Metallurgy

Material for Containing Boiling Liquid Metals. The long-time containment of Hg boiling at 650°C in Cb–1 wt % Zr alloy may be limited by stress corrosion failure of this alloy. Investigation of stress corrosion by Hg in capsule test has shown that cracking is dependent on the amount of Zr present in the Cb and the presence of a tensile stress. A thermal convection loop fabricated of Ta and containing Hg boiling and condensing at 650°C and superheated to 760°C has now operated for more than 12,500 hr (as of May 12, 1964) without any indication of failure. A Cb–1 wt % Zr loop con-

taining Hg boiling and condensing at 760°C and superheated to 870°C has operated for 552 hr (as of May 12, 1964).

The ability of refractory metals to resist corrosion by boiling Na at temperatures >1100°C is being investigated. Since the refractory metals oxidize rapidly at these temperatures and become embrittled by constituents of the atmosphere, these corrosion tests are conducted in a high-vacuum chamber capable of attaining pressures of 10^{-7} torr or lower. Nb–1 wt % Zr in capsules refluxing at 1205°C and in a natural circulation boiling loop operated at 1090°C was not attacked by Na after 5000 hr.

A proposed liquid-metal coolant for the settled bed reactor is a Na-Li alloy. A program has been initiated to study the containment of this alloy in stainless steels.

HFBR Metallurgy. Both curved-plate and flat-plate fuel element tests were satisfactory up to 35 to 40% burnup of the U in 35 wt % U in an Al core. The Dy_2O_3 control rod coupon tested satisfactorily to an exposure of 2×10^{21} thermal neutrons/cm^2; no additional distortion was found.

High-Temperature Properties of Materials

Thermodynamic Properties of Refractory Metal Carbides. Thermodynamic data in the Th-C system have been obtained from measurements on solid electrochemical cells at 800° to 1000°C. The cells employed were of the following types:

1. $Th,ThF_4 \mid CaF_2 \mid ThF_4,ThC_2,C$
2. $Th,ThF_4 \mid CaF_2 \mid ThF_4,ThC_2,ThC$
3. $Th,ThF_4 \mid CaF_2 \mid ThF_4,ThC_x\ (1 \geqslant x \geqslant 0.7)$
4. $Th,ThF_4 \mid CaF_2 \mid ThF_4,ThC_{0.7},Th$

The free energies, entropies, and enthalpies of formation of ThC and ThC_2 were measured. The activities of Th and C in nonstoichiometric ThC between the compositions $ThC_{0.7}$ and ThC have been determined. A reasonable qualitative picture of the bonding in nonstoichiometric ThC has been developed based on the assumption that Th and C form covalent bonds which increase in strength as C is removed from the lattice.

Cesium-Graphite Compounds. A kinetic study of the decomposition of Cs-graphite compounds *in vacuo* has been carried out over the temperature range 400° to 650° C. A tracer technique was used in which the concentration of Cs in the compounds was measured by a scintillation scanning probe which continuously monitored the activity of tracer Cs^{134}.

Table 1

Reaction Sequence for Decomposition of C_8Cs

(1) $5C_8Cs(s) \rightarrow 4C_{10}Cs(s) + Cs(g)$; $\Delta E = 36 \pm 1$ kcal/g-mole

(2) $\frac{4}{7}C_{10}Cs(s) \rightarrow \frac{5}{7}C_{24}Cs(s) + Cs(g)$; $\Delta E = 32 \pm 1$ kcal/g-mole

(3) $3C_{24}Cs(s) \rightarrow 2C_{36}Cs(s) + Cs(g)$; $\Delta E = 32 \pm 1$ kcal/g-mole

(4) $4C_{36}Cs(s) \rightarrow 3C_{48}Cs(s) + Cs(g)$; $\Delta E = 32 \pm 1$ kcal/g-mole

(5) $5C_{48}Cs(s) \rightarrow 4C_{60}Cs(s) + Cs(g)$; $\Delta E = 32 \pm 1$ kcal/g-mole

The kinetic data indicated the existence of a Cs-graphite phase ($C_{10}Cs$) not previously reported. In Table 1 is shown the sequence of reactions through which the decomposition proceeds, along with the activation energy obtained for each reaction. A mechanism for the observed rates of decomposition has been formulated which assumes the rate-limiting process to be the evaporation of Cs from the external surface of the solid.

High-Temperature Physical Properties Measurements. The high-temperature x-ray diffraction equipment has been further modified to make possible more prolonged operation at temperatures up to 3000°C. Lattice parameter data were taken for Re and for ThO_2. These data were fitted to an equation of the form

$$L_T = L_0(1 + \alpha\overline{\Delta T} + \beta\overline{\Delta T}^2)$$

where L_T is the lattice parameter at temperature T, L_0 is the lattice parameter at 20°C, $\overline{\Delta T}$ is $T - 20°$, and α and β are empirical constants. The results are given in Table 2.

Diffusion of Xenon in Carbides. The diffusion of Xe in ZrC powder of varying carbon composition ($ZrC_{0.58}$ to $ZrC_{1.01}$) has been determined at temperatures to 1950°C. The general conclusions that may be drawn are (1) the release of Xe fits a bulk diffusion model, (2) the activation energy for diffusion increases with increasing C content, and (3) at low temperatures (<1800°C) diffusion is more rapid from low C materials than from high C materials.

Alloy Theory and Nature of Solids

Liquid Metals. Late this year, a new program on the properties of alkali metal alloys replaced

Table 2

High-Temperature Lattice Parameters

Material	T_{max}, °C	L_0(Å)	α	β
Re				
a-axis	3000	2.7604±0.0009	(6.27 ±0.20) $\times 10^{-6}$	(4.83 ±0.91) $\times 10^{-10}$
c-axis	3000	4.4590±0.0011	(3.907±0.009)$\times 10^{-6}$	(1.458±0.0014)$\times 10^{-9}$
ThO_2	2400	5.600 ±0.001	(8.87 ±0.19) $\times 10^{-6}$	(6.1 ±1.1) $\times 10^{-10}$

the long-standing project on properties of Bi and Hg alloys. Final results in the latter program are discussed here.

The electrotransport properties of small amounts of Ag and Cr in liquid Bi have been studied. Ag migrates against the flow with a mobility ranging from 1.7×10^{-4} cm²/V-sec at 300°C to 2.4×10^{-4} cm²/V-sec at 600°C. Preliminary values of the diffusion coefficient are 2.8×10^{-5} cm²/sec at 300°C and 7.3×10^{-5} cm²/sec at 600°C. Cr migrates in the same direction as the electron flow with a mobility of $\simeq 6\times10^{-4}$ cm²/V-sec at 500°C, compared to its diffusion coefficient in liquid Bi of $\simeq 3$ to 5×10^{-5} cm²/sec at 500°C.

The electromotive forces (emf's) of solid metal–liquid metal concentration cells (between two different alloys of Fe and Cr in contact with liquid Bi) directly correlate with the electromobility of Fe and Cr in Bi and the known thermodynamics of Fe-Cr alloys.

The solid-liquid interfacial energy (γ) has been shown to be related to the partial molal enthalpy of solution (ΔH) of the solid in the liquid (estimated from solubility measurements) by the simple relationship $\Delta H/\gamma = V/d$ (the molal volume of the solute divided by its atomic diameter). This equation predicted, and experiment proved, embrittlement of Cb by Bi.

A stress-sensitive selective leaching of Zr from Cb–1 wt % Zr by Hg was identified, and the parameters of stress, temperature, and heat treatment were studied.

An equation for liquid-metal dissolution was developed which relates the dissolution rate to free energy changes rather than the concentration gradient.

Electron Microscopic Studies of Fission Fragment Tracks in Thin Metal Films. Calculations show that an isolated crystallite model of a thin film can explain the ability of a film to register tracks. The model indicates that this ability should correlate with the film's electrical resistivity. Experimentally, it has been found that fission fragment tracks are readily observed in films whose resistivities are orders of magnitude larger than bulk resistivity. Films whose resistivities are <10 times bulk resistivity do not show tracks.

Superconductivity. A joint program has been initiated with the Physics Cryogenics Group to study the fundamental and metallurgical aspects of superconducting materials. A low-temperature laboratory has been set up with four experimental units capable of reaching 0.9°K by pumping on He^4. Temperatures down to 0.01°K will be obtained by demagnetization with He^3 pumping used as an intermediate cooling stage. Surface superconductivity was studied in type I and type II superconductors. Groups at BNL and the Radio Corporation of America simultaneously demonstrated the existence of surface superconductivity in type I superconductors. Surface superconductivity was studied by comparing bulk magnetization and ac susceptibility measurements which are capable of high precision.

The effects of surface treatments and coatings on the superconductivity transitions and on the temperature dependence of the Ginzburg-Landau parameter (K) were measured. Surface superconductivity work in progress includes studies on the changes in penetration depth with varying K, changes in the thickness and critical current-carrying capacity of the surface layer as a function of the rate of change of the external magnetic field, and changes in the surface transition in transverse magnetic fields.

Radiation Effects

Effect of Neutron Irradiation on the Mechanical Properties of Body-Centered-Cubic Metals. Apparent contradictions on the effect of neutron irradiation on the parameters of the Petch equation, $\sigma_{ys} = \sigma_i + K_y d^{-1/2}$, which relates the yield strength

of body-centered-cubic metals with the grain size, can be reconciled by considering the neutron exposure and the C concentration. Neutron irradiation produces changes in σ_i at relatively low exposures and in K_y only at higher exposures. In fact, the yield strength of Fe with low ($\approx$30 ppm) C content is virtually independent of grain size after radiation exposure above 10^{18} nvt. C increases the exposure level at which a change in K_y is noted. A ductile-to-brittle transition at 125° to 130°K is produced in Fe with C contents of 30 ppm or greater after irradiation to 2×10^{18} nvt and above. This embrittlement is attributed to the trapping of C atoms by radiation-produced vacancies. Alloying with sufficient Cr or vacuum-remelting prevents embrittlement at this temperature.

Recovery of this brittle transition is initiated by postirradiation anneals of 4 hr or more at 250°C. However, complete recovery of the increase in yield strength requires annealing temperatures of 350° to 400°C.

Studies of mechanical twinning in Fe indicate that twinning is not responsible for (1) the inflection observed in the yield stress vs temperature curve at $\approx$50°K, or (2) the onset of embrittlement. Our data indicate that C inhibits slip and twinning at low temperatures, as does neutron irradiation.

Electron Microscopic Study of the Effects of Neutron Irradiation on the Properties of Iron and Other Body-Centered-Cubic Metals. Specimens of Ferrovac E Fe containing 0.003 wt % C irradiated with fast neutrons ($E>1.45$ MeV) at 60° to 80°C to integrated fluxes of 2×10^{18}, 1×10^{19}, and 2×10^{20} nvt were examined in an RCA EMU-3D electron microscope. The substructure was similar to that of unirradiated specimens. After heating in vacuum at 350°C for 2 hr, the 1×10^{19} and 2×10^{20} nvt specimens contained dark spots $\approx$50 Å in diameter. The density of spots decreased as the temperature of heat treatment was raised, while the diameter of the spots increased. At 400°C and higher the spots could be resolved as dislocation loops. Selected-area electron diffraction studies indicated that the loops lie parallel to the {110} planes of the Fe lattice. At constant temperature, the total area of loops per unit volume rose fairly rapidly with time and then decreased much more slowly. These defects are believed to be vacancies or small clusters of vacancies. The maximum concentration of spots was lower than the concentration of primary knock-ons, and the maximum concentration of vacancies in loops was lower than the concentration of vacancies generated by the irradiation, each by a factor $>10^3$.

Specimens from some Ferrovac E which had been remelted under vacuum to reduce the concentrations of interstitial impurities to $<$0.001 wt %, and irradiated to 2×10^{20} nvt, showed spots in the "as-received" condition. Interstitial impurities affect the mobility of the defects.

It may be concluded that the irradiation-induced defects that have the greatest effect in raising the yield stress and lowering the ductility of Fe are too small to be observed by electron microscopy. The clustered defects large enough to be detected by electron microscopy have a much smaller effect upon the mechanical properties.

Irradiation Effects in Graphite. A model for radiation damage to graphite has been proposed to account for the rate of accumulation of damage as a function of irradiation temperature. The absolute rate of formation of displaced atoms and the migration energy for the single interstitial have been obtained from c-axis, stored energy, thermal resistivity, and dimensional changes. Radiation damage can be removed from graphite by properly selecting the magnitude of the exposure between low-temperature anneals in alternately irradiated and annealed graphite.

CHEMISTRY AND CHEMICAL TECHNOLOGY

Reactor Chemistry

High-Temperature Equilibria. A variety of thermodynamic data was obtained by techniques involving galvanic cells in which the electrolytes consisted of solid or fused salts. Some of these were set up as concentration cells, the junction between the two liquid-salt phases being made through a glass or porcelain membrane permeable only to the cation whose concentration differed. Thus, with a Na porcelain, mixing energies were determined in the systems $NaCl$-$MgCl_2$, $NaCl$-$CaCl_2$, $NaCl$-$BaCl_2$, and $NaCl$-$SrCl_2$; the results are shown graphically in Figure 6. It is noteworthy that the mixtures become nearly ideal as the size of the alkaline earth cation increases. A porcelain in which the conductivity was due to the migration of Li^+ and a glass permeable to K^+ ions were also eventually obtained, and with them similar measurements were made on the systems $LiCl$-$CaCl_2$, $LiCl$-$PbCl_2$, and KCl-$CaCl_2$. A series of

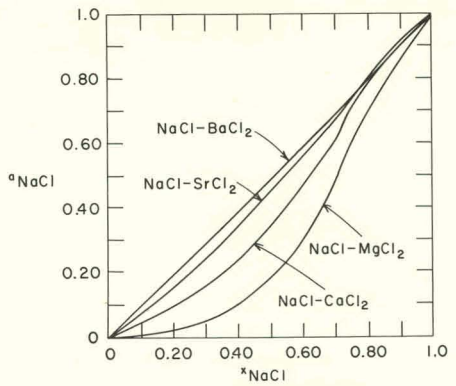


Figure 6. Activity of NaCl in alkaline earth chlorides vs mole fraction at 825°C.

cells containing solid electrolytes was made up for the purpose of determining free energies of formation of salts. An example is the cell Mo|Al,AlF^3(s)|CaF_2(s)|PbF_2(s),Pb(l)|Mo, whose emf is proportional to the difference between the free energies of AlF_3 and PbF_2; the former is well known and the latter can be obtained. Other salts for which this property was determined were CoF_2, $CoCl_2$, NiF_2, and $NiCl_2$.

The absorption spectra of several high-temperature systems were measured. Among these were liquid KNO_3 and $NaNO_3$, for which good ultraviolet data were obtained for the first time by the use of a thin-film technique; and solutions of Cd in $CdCl_2$, which had absorption bands that showed the presence of a subhalide, presumably Cd_2^{++}.

Radiation Chemistry of Fluorocarbons. The series of experiments in which the radiation stability of aromatic and alicyclic fluorocarbons was compared was completed with perfluoronaphthalene, $C_{10}F_8$. The *G* value for destruction of starting material was 1.3 molecules per 100 eV of energy absorbed (from a 1.5-MeV electron beam). This is about the same as the figure for biphenyl (1.4) and slightly less than that for the alicyclic analogue, perfluoronaphthalene (1.7). Almost all the radiolysis product was material of higher molecular weight than $C_{10}F_8$.

Perfluorobiphenyl was exposed to Co^{60} gamma rays at 450°C, for comparison with results at 100°. Its radiation stability remained good at the higher temperature. The over-all *G* was 1.5, as compared with 1.4 at the lower temperature, and *G* for gas production was $\approx$0.002.

Noble Gas Chemistry. The applicability of ionizing radiation as a catalyst in the synthesis of noble gas compounds was further investigated. Krypton difluoride was prepared for the first time in weighable amounts by irradiating a mixture of the elements in a vessel whose walls were cooled to −140°C. Both electron and proton beams were effective, but the latter gave greater yields because of their more complete absorption in a short path through a gas phase. The compound proved to be a white solid, capable of being sublimed in a vacuum at −30° to −40°C. It is not stable at room temperature, differing in this respect from XeF_2.

Mixtures of Ar and F given similar radiation treatment did not yield any isolatable compound.

Chemical Technology

Mechanism of Graphite Formation. In studying the mechanism of graphite formation from H_2-hydrocarbon mixtures, it was found that the C/H ratio and not the initial hydrocarbon composition determines whether a carbon sublimes from, or deposits on, a graphite filament at a given temperature. This sublimation temperature was experimentally investigated at 0.1 atm pressure as a function of the C/H ratio in the temperature range 2500° to 2800°K, with CH_4 and C_2H_2 used as the hydrocarbons, and it was found to agree with thermodynamic predictions. Addition of Ar decreased the C/H ratio at which graphite deposits, but increased the percent of C_2H_2 in the hydrocarbon mixture. In carrying out these experiments using C+H_2, it was found that the rate of reaction increased very rapidly above 2750°K, where the mechanism appears to involve the evaporation of C_1, C_2, and C_3 species. In flash heating experiments, it was found that C_2H_2 can be formed from C and H_2 at energy requirements of <300 kcal/mole (4.0 kWh/lb).

Nitrofluor Volatility Process. The Monel equipment for investigating the dissolution behavior of kilogram amounts of U-Zr alloy fuel was completed and leak-tested. Operation of the equipment was begun toward the end of the fiscal year, after the fume scrubber for the ventilating system had been completed. The dissolving agent used is the azeotropic residue (bp=95°C) produced by distillation of a mixture of NOCl and HF. This product was formerly thought to be NOF·3HF, but spectral studies have shown that it also contains a relatively small amount of N_2O_3.

Experiments concerned with the volatilization of Pu from dissolved UO_2 power reactor fuel have

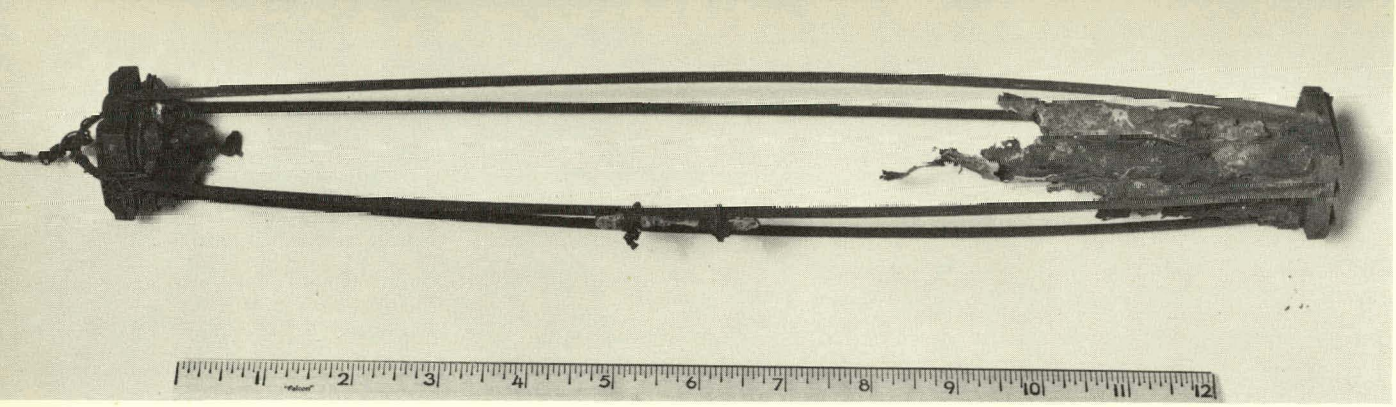


Figure 7. Nine-rod simulated fuel element subassembly after oxidation.

shown that Pu does not form a volatile compound upon treatment of the dissolver residue with NOF or with the vapor from the 95°C azeotrope. U is readily separated as $NOUF_6$ by this treatment at 400°C. Tests showed that essentially all the Pu in the residue can be volatilized by treatment with pure F_2 at 500°C. The separation is not appreciably affected by the presence of fission product elements.

The corrosion kinetics of unstressed Monel and Ni in HF solutions containing up to 30 mole % NO_2 was studied by using a technique based on the change in electrical resistance of a wire specimen. A protective film forms on Monel in 30 mole % NO_2 solution in a matter of hours at 125° and 150°C. The film on Ni is not as protective, and on continued exposure corrosion occurs at a linear rate of 2 to 3 mils/yr. Both films resist attack at temperatures up to 150°C and in solutions containing as little as 10 mole % NO_2.

The dissolution of UO_2 in HF solution containing 25 mole % NO_2 does not measurably increase the corrosion of Ni, except around 125°C where the formation of a protective film is not as rapid. Monel corrosion increases considerably in the presence of dissolved UO_2, but the effect is reduced when a larger amount is dissolved or when the temperature is increased. The behavior of Monel and Ni in process equipment may be considerably different than reported above, since stress may cause breakdown of the protective film. A new series of experiments to study this effect is under way.

Volatility Process Development. The Fluid-Bed Volatility Reprocessing Pilot Plant has been completed and is being operated with use of unirradiated graphite matrix fuel. U recovery >99% has been obtained.

The process, as applied to graphite fuel, involves two steps: oxidation at 700°C to remove C as CO_2, followed by fluorination at 450°C to recover U as UF_6. Each step is carried out in a separate 4-in.-diam reactor. Since the oxidation step is limiting with respect to throughput, it is carried out on a continuous basis, whereas the fluorination is carried out batchwise. In such a system comparatively high throughput rates may be achieved in a relatively small unit. Other advantages accruing from the 2-reactor system are that corrosion and problems associated with thermal cycling are reduced to a minimum.

In bench-scale studies on the recovery of U from SS-clad UO_2 fuel by means of fluidized beds, >99% U recoveries have been achieved. In the decladding step, the SS is converted to oxide by oxygen at ≈725°C in a fluidized alumina bed containing ≈5% iron fluoride. The exposed U is then recovered as UF_6 by contacting the bed with fluorine under fluidized conditions. Encouraging results have also been obtained on decladding clusters of rods that simulate actual fuel element subassemblies. In Figure 7 a rod cluster is shown after the oxidation step. Experiments are currently directed toward obtaining information required for demonstration of this process on an engineering scale in the Volatility Reprocessing Pilot Plant.

Ultimate Waste Disposal. Efforts at Brookhaven involving both bench-scale and pilot-plant operations have been directed toward the building of a prototype at Hanford to demonstrate the phosphate glass process as a method for disposal of radioactive waste.

During the fall of 1963, several extended runs were made in the phosphate-glass pilot plant. These runs had a threefold purpose, i.e., to provide data for the establishment of more comprehensive design criteria, to establish the need for additional plant instrumentation, and to determine more thoroughly the operational parameters essential to process control.

At the conclusion of these runs, the plant, having given 900 hr of glassmaking service, was shut

down so that the instrumentation could be revised in accordance with joint recommendations of Hanford and Brookhaven.

As part of the program to determine the feasibility of the Brookhaven phosphate glass process, a small hot cell experiment will be run at Hanford with high-level Purex waste. The bench-scale equipment designed for preliminary cold runs has been developed and thoroughly tested at Brookhaven over a period of several hundred hours.

Release of Fission Products From Nuclear Fuels. A thorough understanding of the factors affecting fission product behavior, particularly that of iodine, is of prime importance in assessing the consequences of a potential nuclear reactor accident. During the year, iodine transport phenomena and chemical reactions during release were studied in detail.

The release of iodine from metallic U in steam is accompanied by H_2 formation. An average of $80\pm10\%$ of the iodine released from U heated in the range 1100° to 1300°C was collected as an iodide, $\approx1\%$ as iodate and periodate, and the remainder as elemental iodine. The majority of the released iodine undoubtedly reacted with H_2 to form HI, as predicted theoretically. In contrast, an average of $85\pm15\%$ of the iodine released from UO_2 heated under identical conditions was collected as elemental iodine, $\approx\frac{1}{2}\%$ as iodate and periodate, and the remainder as an iodide. This was to be expected, since little H_2 formed during the conversion of UO_2 to $UO_{2.2}$, the stable oxide under these conditions.

Additional data were obtained as further evidence that a uranium iodide is released from U heated to 1200°C in He. At 1800°C the iodide and elemental iodine were released together, since the iodide is partly dissociated at the higher temperature. The iodide condensed on surfaces in the neighborhood of 300°C, while the elemental iodine was relatively volatile at much lower temperatures.

A program was initiated to study the diffusion of iodine in hypostoichiometric UC. The current interest in UC, particularly for use in liquid-metal and fast reactors, prompted this investigation. Diffusion coefficients ranging from 6.4×10^{-13} cm^2/sec at 1400°C to 5.3×10^{-10} cm^2/sec at 1735°C were measured; the activation energy for this process is ≈133 kcal.

Liquid-Metal Heat Transfer Research

The heat transfer research program at Brookhaven is restricted almost entirely to convective heat transfer between surfaces and flowing liquid metals. For the past several years there have been continuing studies, both theoretical and experimental, of the general case of heat transfer to liquid metals flowing through rod bundles, owing to its direct relevance to the design of liquid-metal cooled reactors and their associated heat-exchange equipment. For the particular case of in-line flow, the following semiempirical equation, based on theoretical analysis, is now recommended for bundles having equilateral triangular spacing.

$$\mathrm{Nu}=\alpha+\beta(\bar{\psi}\mathrm{Pe})^{\gamma},$$

where

$\mathrm{Nu} = (hD_e)/k$ = Nusselt number,
h = heat transfer coefficient,
D_e = equivalent diameter of bundle,
k = thermal conductivity,
$\alpha = 6.66+3.126(P/D)+1.184(P/D)^2$,
$\beta = 0.0155$,
$\gamma = 0.86$,
P = distance between rod centers,
D = o.d. of rods,
$\bar{\psi}$ = effective average value of ψ,
ψ = ratio of eddy diffusivity of heat to that of momentum,
$\mathrm{Pe} = (D_e v_a \rho C_p)/k$ = Peclet number,
v_a = average linear velocity,
ρ = density of liquid metal,
C_p = specific heat,
Pr = Prandtl number $= C_p\mu/k$, and
μ = viscosity.

The equation above is compared in Figure 8 with recent experimental results obtained at Brook-

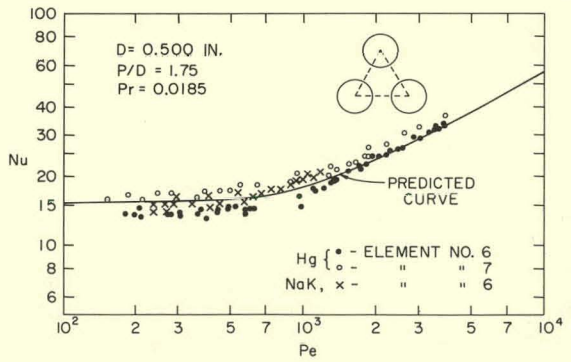


Figure 8. Heat transfer to liquid metals flowing in-line through unbaffled rod bundles under conditions of uniform heat flux and fully established turbulent flow. The data points for mercury were taken about a year apart on two different test elements, both wetted by the mercury.

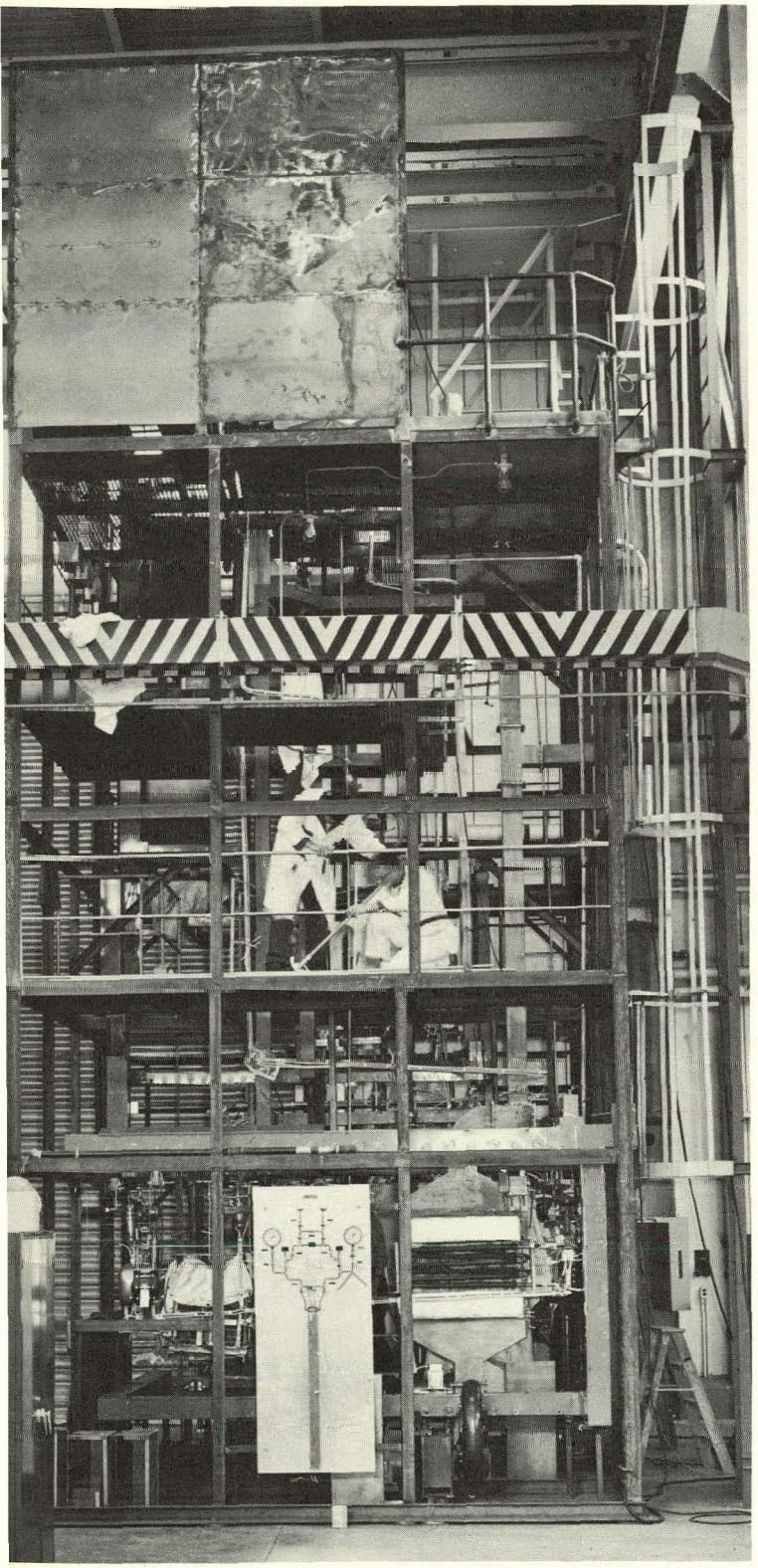


Figure 9. Boiling potassium heat transfer research facility during latter stages of construction.

haven on both Hg and NaK. The agreement between theory and experiment is seen to be very good.

Preliminary to starting an experimental project to study heat transfer to NaK flowing at right angles through a rod bundle, a theoretical study was carried out. The following equation was developed for predicting average heat transfer coefficients for liquid metals flowing at various angles across rod bundles (or tube banks).

$$\mathrm{Nu} = 0.958(\phi_1/D)^{1/2}(\mathrm{Pe})^{1/2}\left[\frac{\sin\theta + \sin^2\theta}{1 + \sin^2\theta}\right]^{1/2},$$

where

$\mathrm{Nu} = hD/k$ = Nusselt number,
h = coefficient based on average rod surface temperature,
ϕ_1 = unit hydrodynamic potential at the rear stagnation point of a rod, and
θ = angle of approach, zero for parallel flow and 90° for normal cross flow.

The above equation agrees quite well with experimental results obtained some years ago at Brookhaven for cross flow of Hg through a staggered rod bundle. At that time only the rod under study was heated; in the new study with NaK, all the rods will be heated.

The purpose of the largest experimental project in the Heat Transfer Group is to obtain fundamental heat transfer information on forced-convection boiling and condensation of K at temperatures up to 982°C (1800°F). Since the facility for this work (Figure 9) was completed and placed in operation only in June 1964, results are not yet available.

As part of the general research program on boiling liquid-metal heat transfer at Brookhaven, a theory was developed during the past year for predicting boiling coefficients under conditions of net vapor generation and forced convection. The correlation was found to be in fair agreement with early experimental results on Na and K obtained at other laboratories.

APPLIED RADIATION

Radiation Effects in Organic Solids

The electron spin resonance (ESR) spectra of powdered and single-crystal samples of acrylamide irradiated and examined at −196°C indicate that the radical has the same structure as that formed

Table 3

G Values for Gas Formation

Toluene	0.16
Toluene-d_3	.11
Toluene-d_5	.11
Toluene-d_8	.06
Toluene and toluene-d_3 (equimolar)	.14
Toluene and toluene-d_8 (equimolar)	.11
Toluene-d_3 and toluene-d_8 (equimolar)	.10

by loss of an alpha hydrogen from propionamide. This is evidence of the scavenging of hydrogen atoms by acrylamide and explains the low-temperature hydrogen yield obtained in solid solutions of acrylamide in propionamide noted in last year's annual report.

Between $-196°$ and $-20°$C, the temperature above which measurable postirradiation polymerization is known to occur, the orientational dependence of the ESR spectrum shows that the free radical can add at most one monomer unit, probably along the crystallographic *b*-axis. At $-20°$C and above, thermal motion sufficient for polymerization occurs and the directional dependence of the ESR spectrum disappears.

It has been found that doses of 1 to 2 million rads can effect almost 100% polymerization of solid trioxane, contrary to a reported upper limit of 60 to 70% conversion. The reaction is characterized by a high degree of irreproducibility.

Radiation Chemistry of Aromatics

The study of the radiolysis of pure toluene has been completed. The data obtained are given in BNL 823 (S-65).

The results of the radiolysis of benzene-toluene mixtures indicate that benzene has a slight protective effect in the radiolysis of toluene.

The radiolysis of deuterated toluene was completed during fiscal 1964; however, all the data have not been analyzed. Table 3 lists the *G* values for total gas formation for the various materials and mixtures investigated. Table 4 lists the isotopic composition of the hydrogen and methane evolved during irradiation of these materials.

Polymerization Mechanisms

A linear dependence of optical density at 610 mμ for solutions of the sodium salt of anthracene in tetrahydrofuran (1.4 to 17.5 $\times 10^{-6}$ moles/liter) and the behavior of equivalent conductance at 30°C over the same concentration range lead to the following conclusions: (1) the molar extinction coefficient is 3.60×10^4, (2) the reduction of anthracene by Na is quantitative, and (3) the dissociation of ion pairs into conducting ions has an equilibrium constant of $\approx 5 \times 10^{-7}$.

The liquid-phase radiation polymerizations of highly purified and exhaustively dried styrene and α-methylstyrene show extreme sensitivity to traces of water. Rates of polymerization of styrene as high as 57% per megarad have been observed at 0°C and 2.24×10^5 rads/hr, and as high as 30% per megarad for the substituted monomer. The polymerization rate of styrene under these conditions appears to depend linearly on the dose rate up to 3×10^6 rads/hr, while the average molecular weight is constant. When methyl methacrylate was studied under similar conditions of preparation, no enhancement in the rate of polymerization was observed.

Chemonuclear Reactors

Dosimetry. With use of the N_2O gas dosimeter, a fission fragment energy deposition efficiency of 61% for a 2-dimensional array of 3-μ U-bearing glass fiber at a loading of 0.29 mg/cm^2 was ob-

Table 4

Isotopic Composition of Hydrogen and Methane Evolved During Irradiation

	H_2	HD	D_2	CD_3H	CD_2H_2	CDH_3	CH_4	CD_4
Toluene-d_3	32	48	20	47	>1	>3	4	45
Toluene-d_5	61	33	6	–	–	8	90	–
Toluene-d_8	>1	>2	97	6	>1	>2	–	92
Toluene-d_3 and toluene-d_8	14	41	46	39	>2	>3	>2	53
Toluene and toluene-d_3	69	26	5	32	>1	34	32	>2
Toluene and toluene-d_8	51	34	16	41	–	≈6	49	5

tained. An energy deposition efficiency of 63% was observed for a 20 wt % U-Pd alloy foil. A plot of efficiency as a function of metal foil thickness for U-Al and U-Pd alloys is shown in Figure 10, together with theoretical values. The energy deposition efficiency for these 2-dimensional foils falls between values approximated by analytical expressions based on the linear and quadratic energy loss dependence of the range-energy curves, with the assumption of a constant G value for chemical conversion along the length of the fission track.

Fission Fragment and Reactor Radiation Chemistry. The formation of NO_2 and N_2O from synthetic air mixtures is being studied as a function of fission fragment and reactor irradiation conditions. Figure 11 gives the NO_2 and N_2O yields as a function of the total dose for mixed fission fragment plus reactor irradiation. The initial G values based on these data are $G_{NO_2} \approx 0.9$ and $G_{N_2O} \approx 0.6$ and appear to be independent of pressure. The steady-state concentration at 5 atm pressure is 19.7% for NO_2 and 6.2% for N_2O. A steady state has not been reached in the high-pressure, 68-atm experiments, although a concentration high enough to condense liquid N_2O_4 has been achieved. Studies are in progress to determine the effect of varying N_2-O_2 concentration and of increasing temperatures.

Chemonuclear Source and Fuel Development. Metal alloys containing significant concentrations of U^{235} for chemonuclear applications are being developed. A solid solution of U in Pd has been rolled to 2.5-μ (0.1-mil) thickness on a Sendzimir mill and has been further etched to 1.5 μ. Tests in air at 1000°F indicated some surface oxidation. In-pile tests up to 0.5% burnup indicated a small amount of corrosion in air. Larger amounts of corrosion have been noted in atmospheres containing high concentrations of NO_2. Coatings of Al, Al_2O_3, and SiO improve the resistance of the foil to corrosion. High-burnup studies indicate that radiation damage alone may not be severe. Further radiation damage studies are being made with different coatings, with other alloys of U, and with cermets of UO_2 in metal matrices.

Fabrication of a structurally stable honeycomb array of 4-μ (0.18-mil), 20 wt % U-Pd similar to the model shown in Figure 12 has been achieved. Aerodynamic tests on single thin foils indicate that the controlling stability feature is the length and prestressing of the unsupported section of foil. Pressure loss measurements for honeycomb arrays have also been made.

Chemonuclear In-Pile Research Loop. The loop (Figure 13) is designed to be a versatile facility for handling light gases at pressures up to 1000 psig and temperatures from −30° to 1000°F in contact with fixed fuel elements. The capacity of the loop is $\approx$66 g of U^{235} to give a maximum power level of 5100 W. The design has been completed, and most of the equipment is in the process of being fabricated. A critical item is the gas circulators which will feature a corrosion-resistant, completely sealed gas bearing design. Start-up of the loop is scheduled for the summer of 1965.

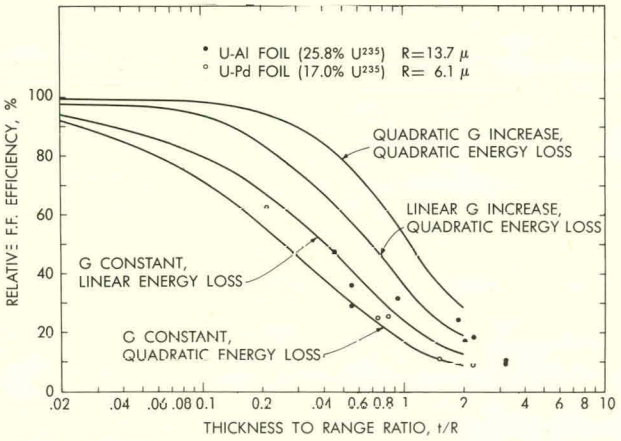


Figure 10. Relative fission fragment efficiency for foils as a function of thickness to range ratio.

Radiation Chemical Processing

Ethylene Polymerization. Following initial experiments with a falling pressure technique, a series of Co^{60} gamma radiation-induced polymerization experiments has been carried out under constant pressure conditions. The effects of dose rates between 5.8×10^4 and 8.47×10^5 rads/hr, doses ranging from 0.1 to 1×10^6 rads, and pressures from 2500 to 10,000 psig have been tested. The rate of polymerization is being measured as a function of pressure and intensity. The physical properties of the polymers are being measured and correlated. The molecular weight, ranging into the millions as determined by means of intrinsic viscosity, increases with decreasing dose rate and increases with pressure in the range 5000 to 10,000 psig. The densities of the polymers are in the intermediate range 0.93 to 0.94. Most of the polymers have been found to be soluble in Decalin at 135°C.

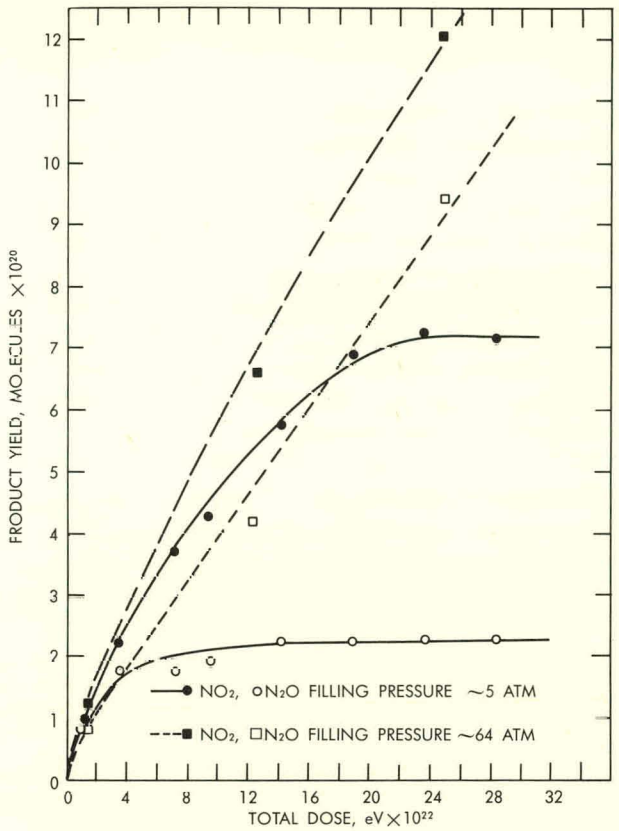


Figure 11. Fission fragment plus reactor irradiation of synthetic air ($N_2 = 77.3\%$, $O_2 = 22.7\%$). Temperature, $\approx 40°C$.

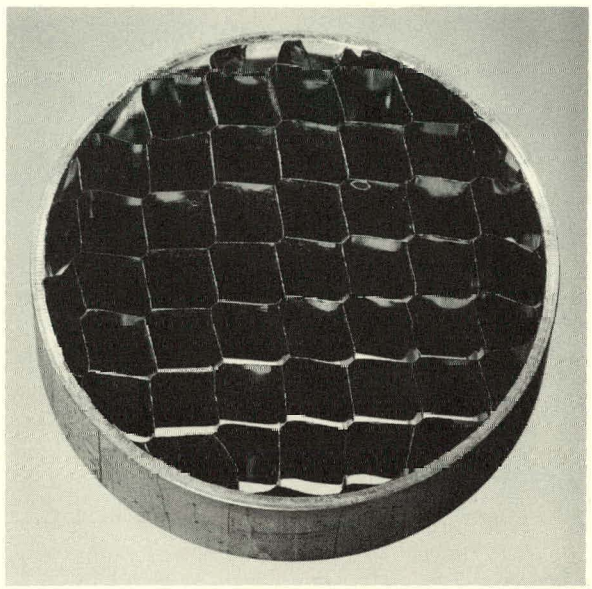


Figure 12. Honeycomb fuel assembly model using 0.255-mil stainless steel foil.

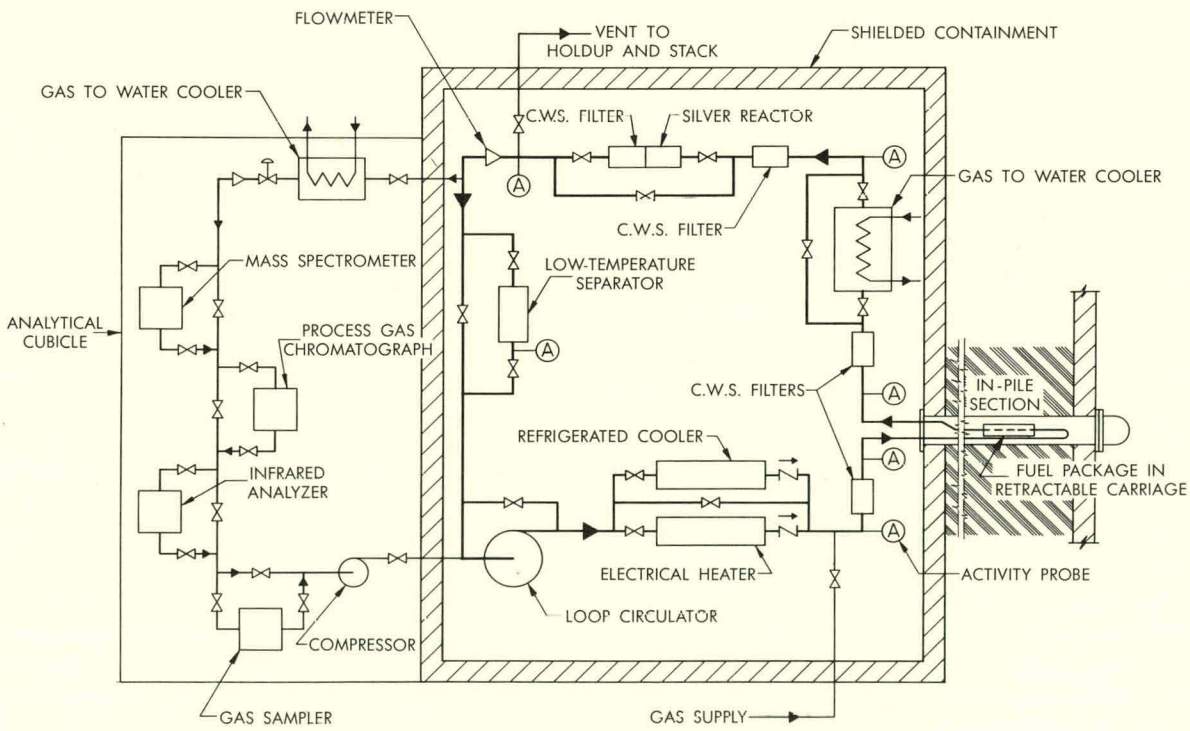


Figure 13. Flow sheet of Brookhaven chemonuclear in-pile research loop.

Ethylene–Carbon Monoxide Copolymerization. An extensive study of the Co^{60} gamma radiation-induced synthesis of copolymers of CO and ethylene (E) has been made. The final copolymer composition as a function of the initial E/CO composition from 0.05 to 45 has been determined. The polymers exhibit a polyketone structure with an E/CO ratio between 1 and 2 when initial composition is >0.23. It has been possible to produce a copolymer with an E/CO ratio of <1 when the initial composition was highly enriched in CO. The reactivity ratio for the 1:1 E/CO mixture decreases with increasing temperature, and the rate of polymerization also decreases. Measurements on a differential scanning calorimeter indicate a melting point in the range 187° to 213°C for the 1:1 E/CO copolymer produced at 2500 and 10,000 psi. Decomposition occurs at 290°C. The polymer has been found to be insoluble in all the common solvents.

Ethylene–Sulfur Dioxide Copolymerization. Exploratory measurement indicated the formation of a polysulfone on the irradiation of ethylene-SO_2 and ethylene-SO_2-CO mixtures. Transition and decomposition of this material occurs at 237° and 367°C, respectively.

Chemical Irradiator Design. Equations were derived permitting the calculation of the transient and steady-state concentrations of reactive intermediates in response to intermittent (square wave) irradiation as a function of frequency of irradiation, relative duration of light and dark periods, irradiator type, and reactor mechanism. The irradiators included were the batch irradiator, the continuous stirred tank irradiator (both with intermittent sources), and the tubular irradiator with partial or total recycle. The effect of mixing in the direction of flow in the tubular irradiator with recycle was briefly examined. The reaction mechanisms treated included first- and second-order reactions of intermediates and consecutive first-order reactions.

Calculations of the ratio of conversion in the presence of perfect mixing to conversion in the absence of mixing have been made for slab and annular reactors with sources of exponentially attenuated radiation and of constant energy loss radiation. For the two types of radiation at equal optical thicknesses (reactor thickness measured in units of radiation mean free path or particle range), the ratio is greater for the annulus than for the slab, and it is greater for constant energy loss radiation than for exponentially attenuated radiation. Mixing changes conversion by a maximum of 100% at optical thicknesses of 16 for the slab and 9.2 for the annulus (ratio of outer to inner radius is 5) with exponentially attenuated radiation and at optical thicknesses of 4 for the slab and 2.4 for the same annulus with constant energy loss radiation.

Two experiments have been initiated to study the mixing effect just described. One involves a continuous tubular reactor and a liquid-phase photochlorination. The other experiment involves a photopolymerization in a stirred tank reactor.

Radiation Engineering

High Intensity Radiation Development Laboratory. The preparation cell is in operation. Sources containing 300,000 curies of Co^{60}, received from the Engineering Test Reactor (ETR), were removed from their reactor irradiation containers, remotely encapsulated in SS envelopes (see Figures 14 and 15), and finally leak-tested. The second encapsulation of these sources has been completed; 36,000 curies of Co^{60} have been shipped to the University of Florida, and 15,000 curies have been allocated to the University of Michigan.

Sources containing 217,000 curies of Cs^{137}, to be used for experimental purposes in the HIRDL, were received from ORNL. BNL standard sources containing 225,000 curies of Co^{60} were received from the Savannah River Plant. Following a second encapsulation, these will be shipped to Gloucester, Mass., for use in the Marine Products Development Irradiator (MPDI) for the Bureau of Commercial Fisheries.

BNL Standard Source. The standard Co^{60} source developed at Brookhaven (Figure 16) will be used in the Bulk Grain Irradiator and a portable irradiator, in addition to the MPDI. This source has been further improved by bonding the first SS encapsulation to the Co (Figure 17).

Irradiator Design. Conceptual design studies for a shipboard Co^{60} radiopasteurizer and a bulk grain irradiator have been completed. Also completed were the design of an interim research irradiator, to be installed on the campus of the University of Hawaii during fiscal 1965, and the design of a small, 16-ton, portable irradiator, of which two are to be constructed during fiscal 1965.

Gamma Irradiation Services and Operations. In addition to the standard irradiation services

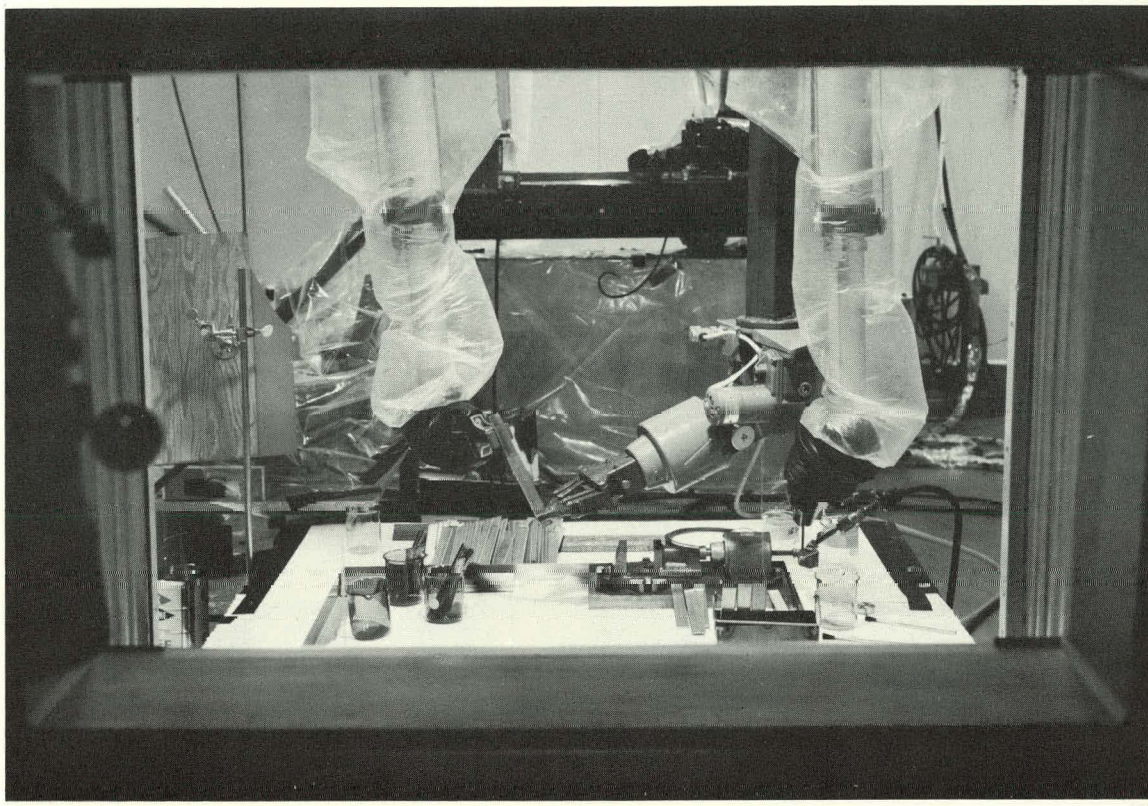


Figure 14. Loading ETR Co^{60} sources into stainless steel envelopes prior to welding.

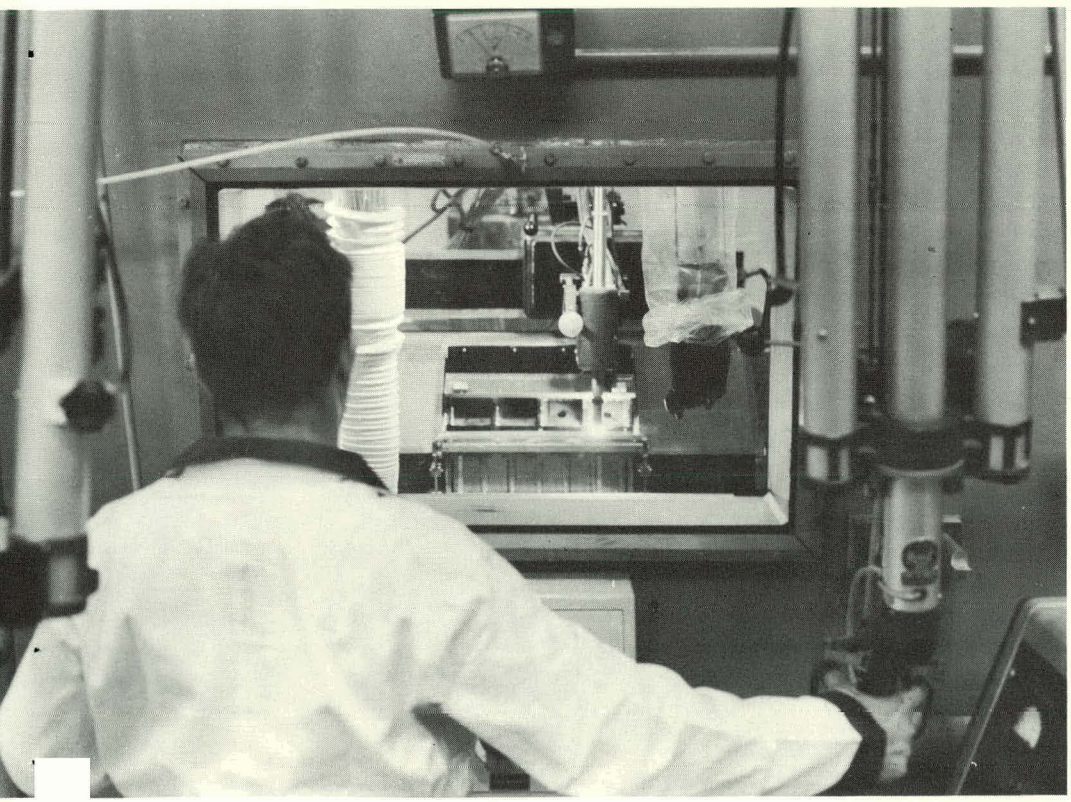


Figure 15. Remote welding of stainless steel encapsulations.

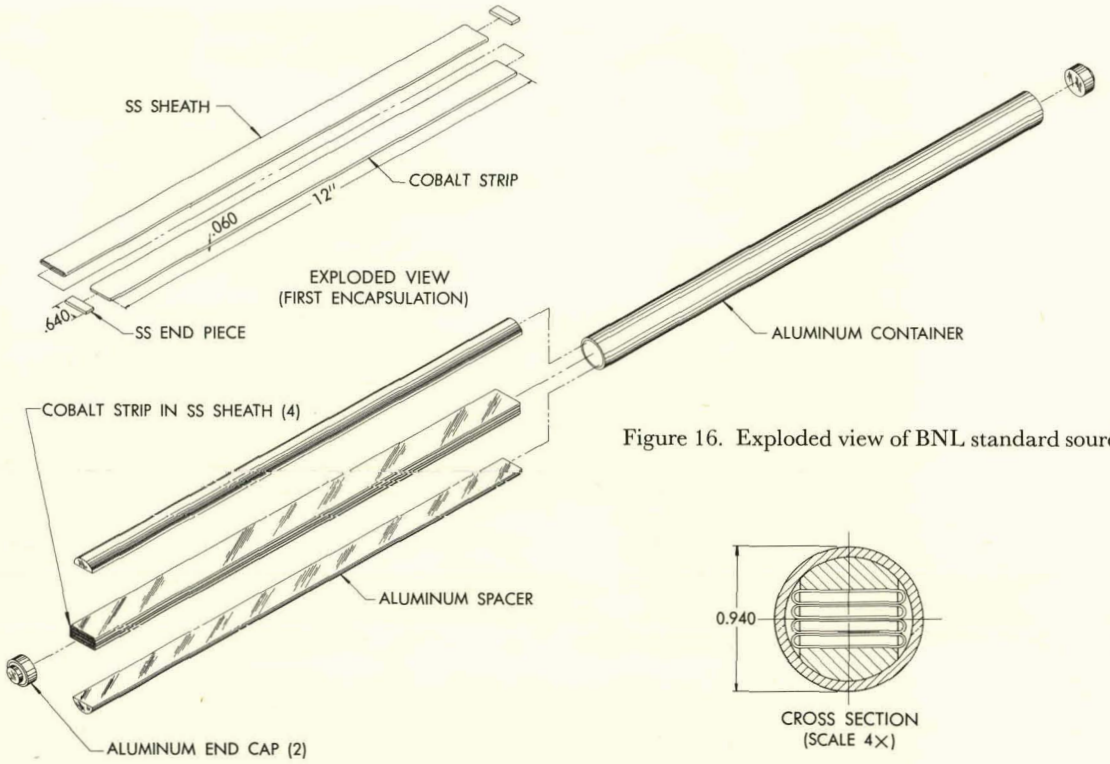


Figure 16. Exploded view of BNL standard source.

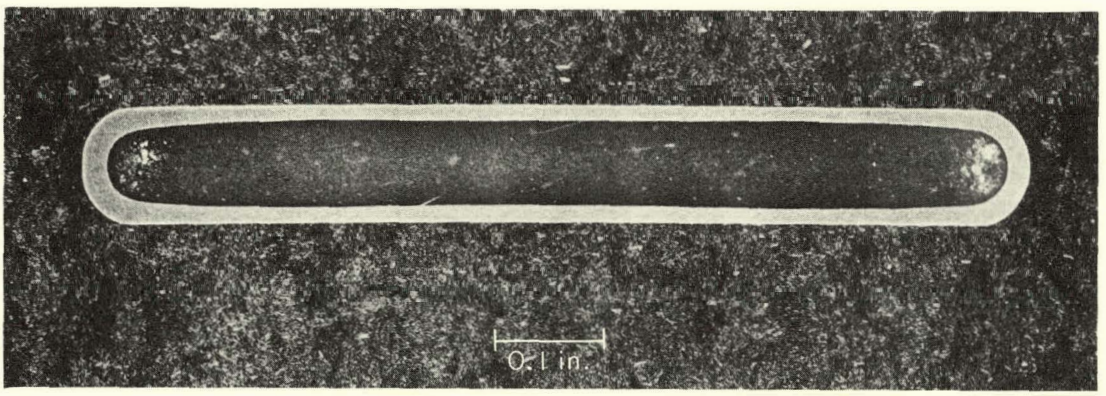


Figure 17. Cross section of cobalt metal clad with stainless steel by coextrusion.

provided during the year, 16 BNL flat sources, each containing ≈123 curies of Co^{60}, were doubly encapsulated and shipped to Mission, Texas, for use by the U.S. Department of Agriculture in its screwworm fly eradication program. A 1600-curie Co^{60} ETR source was calibrated, tested, and sent to Texas A & M University to be used by its Physics Department for research studies. A 600-curie Co^{60} tubular source was lent to the U.S. Department of Agriculture for use at the Plum Island Animal Disease Laboratory in its research program.

Source Assay and Calibration. An ETR Co^{60} source assay and calibration unit (Figure 18) has been constructed and is now in operation. The unit is equipped with an n-on-p solar-cell dose-rate detector and provides information on both the activity distribution and total activity of each ETR strip. To date this analyzer has catalogued ≈700 strips of ETR Co^{60}.

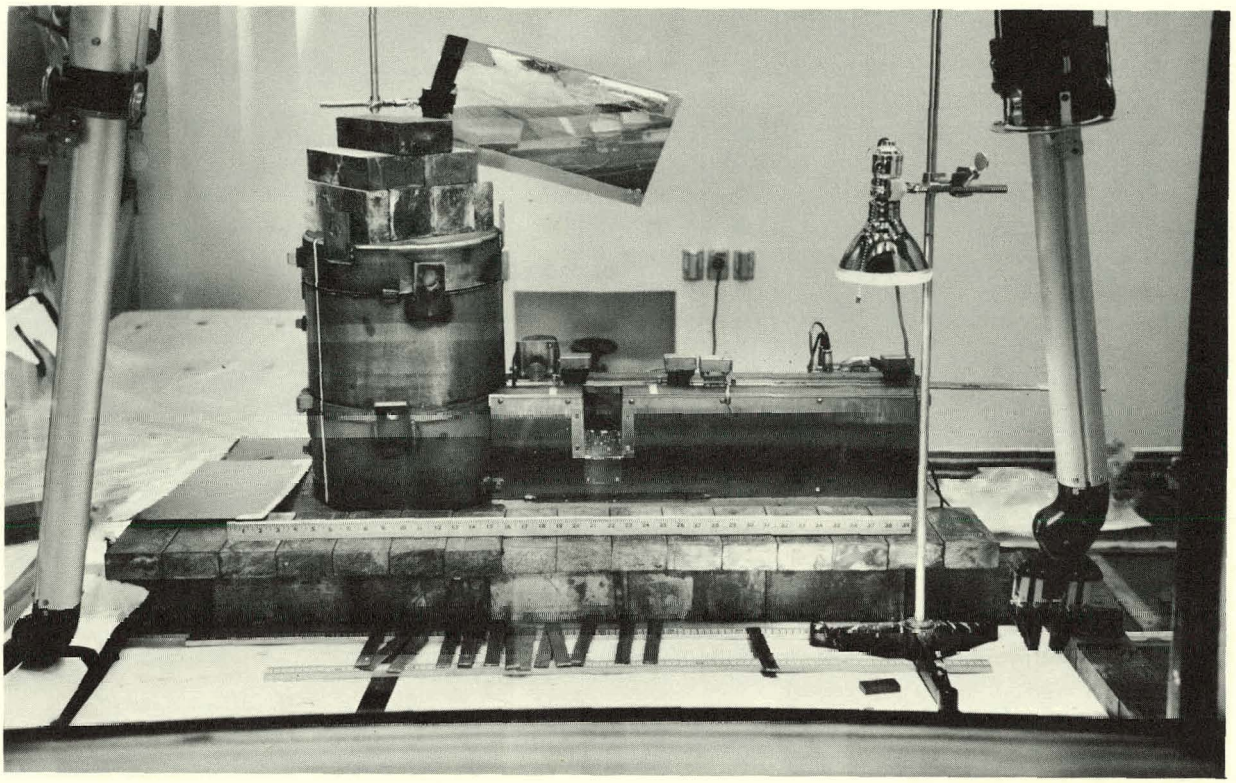


Figure 18. Calibration unit seen through remote viewing window.

Electrical Discharge in Shielding Glass. A mathematical model has been developed which is a good order-of-magnitude approximation of the discharge phenomenon. Experimental studies indicate that an electronic process associated with storage of electrons in color centers similar to those of Ce is involved in the discharge phenomenon. The presence of Pb and similar heavy ions in glass may cause buildup of stress and thus decrease the dielectric breakdown strength. Na or other highly mobile ions may decrease the buildup of net charge, inhibit browning of the glass, and increase ionic conductivity.

Measurement of Self-Absorption of Co^{60} Sources. A large calorimeter, which was designed, constructed, and tested at BNL, has been successfully used to measure the self-absorption and total curie content of the ETR Al-clad Co^{60} sources.

A second calorimeter, capable of handling the larger BNL standard source, has been designed and is being constructed.

Gamma Monochromator. Development work has proceeded on a gamma monochromator, an instrument to produce fairly monochromatic, variable-energy gamma rays by Compton scattering from an intense radionuclide gamma source. Energy resolutions of $\approx$1 or 2% are expected to be attained at intensities equivalent to a millicurie for a high resolution form of the instrument, with correspondingly higher yields at lower resolutions. The instrument is expected to be useful in dosimetry studies, radiobiology, and solid-state and nuclear physics.

HOT LABORATORY

Isotopes

The feasibility of making a generator from which Te^{127g}, Te^{129g}, and Te^{131g} can be milked from their respective longer-lived metastable isomeric parents was shown. The anomalous adsorption and elution behavior of I^{132} and Te^{132} with alumina was shown to be due to differences in behavior of Te(IV) and Te(VI) on alumina and to oxidation of Te(IV) to Te(VI).

Efforts to prepare ultrahigh specific activity Mg^{28} by recoil showed that recoil does occur, the range of the most energetic Mg^{28} atom being 0.4 to 2.4

mg/cm^2. The excitation functions for $Mg^{26}(t,p)Mg^{28}$ and $Mg^{25}(t,\alpha)Na^{24}$ were measured; they are virtually identical.

The $Ar^{40}(\alpha,2p)Ar^{42}$ and $Ar^{40}(t,p)Ar^{42}$ reactions were detected, the latter with reactor-produced tritons, and this has paved the way for a possible practical generator from which carrier-free K^{42} might be milked.

A new extended table of nuclidic masses from which unknown masses may be estimated was constructed. The method used was based on the known parabolic relationship of masses at constant *A*. The standard deviation between calculated and measured masses was 0.35 MeV for 763 cases. Pairing corrections (δ's) for protons and neutrons were also calculated.

Previously unknown Ir^{196} was successfully prepared by the reaction $Pt^{198}(d,\alpha)Ir^{196}$ and was found to have a half-life of $\approx$90 min, a gamma spectrum similar in some respects to that of Au^{196}, and an excitation function for formation different from that for $Pt^{196}(d,\alpha)Ir^{194}$.

Useful methods were found for extracting Ga^{68} from the EDTA complex furnished by Brookhaven's Ga^{68} generators.

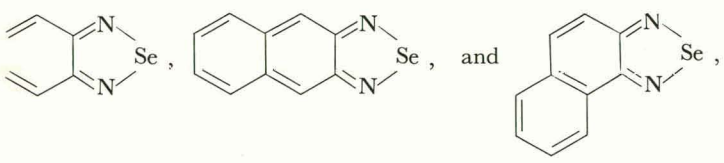
A method was developed for preparing carrier-free Cs^{129} and Cs^{132} from the $I^{127}(\alpha,2n)Cs^{129}$ and $I^{129}(\alpha,n)Cs^{132}$ reactions, respectively.

Analytical Chemistry

The proximity of the half-wave potentials of Pb and Cd at the dropping Hg electrode in molten $LiNO_3$-KNO_3 eutectic was shown to be due to a specific effect of the molten nitrate environment on one or both of the solute ions rather than to a temperature effect, which is small.

A mathematical model for current reversal chronopotentiometry was developed and analyzed with use of the IBM 7094 computer. The model was successfully applied to the disproportionation of U(V) in perchloric acid solution. This approach can be used for studying analogous systems, with rate constants ranging from 1 to 10^5 liters/mole-sec.

Free radicals of the complexes between Se and derivatives of 1,2-diaminobenzene



were prepared by electrolytic or Na reduction. They are believed to be the first anion radicals containing Se to be reported. In all cases only one species was formed initially.

Thus far a study of the synergistic effects between thenoyltrifluoroacetone (HT) and tri-*n*-octylamine (R_3N) in the extraction of americium indicates that two species, R_3NHCl and R_3NHT, cause the enhanced extractive effect of one solvent in the presence of the other.

Methods developed included those for determining Th^{228}, Th^{230}, and Th^{232} in Thorotrast; O_2 in Na; Zr, Nb, and Mg in Hg; and S in "Tc^{99m} colloid" ($Tc_2{}^{99m}S_7$ in sulfur emulsion).

Hot Laboratory Operations

One of the functions of the Hot Laboratory Division is the production of certain isotopes requiring chemical processing following irradiation. Table 5 is a 3-year summary of this effort. The

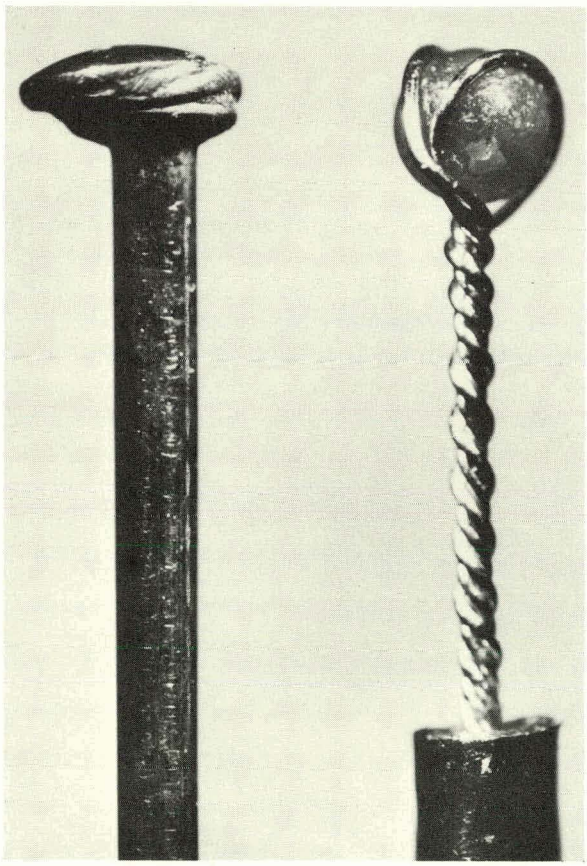


Figure 19. Holder developed for Y^{90} bead (right). Pin head (left) is shown for size comparison.

Table 5

Production of Special Isotopes by Hot Laboratory Division

	Fiscal 1964				Fiscal 1963				Fiscal 1962			
	No. of shipments		Activity, mC		No. of shipments		Activity, mC		No. of shipments		Activity, mC	
	On site	Off site	On site	Off site	On site	Off site	On site	Off site	On site	Off site	On site	Off site
Al^{28} generators	–	–	–	–	–	3	–	0.3	–	–	–	–
Ar^{38}	–	5[a]	–	0.24[b]	–	8	–	0.3[b]	–	8	–	0.24[b]
Cu^{67}	–	1	–	1	–	–	–	–	–	–	–	–
F^{18}	–	–	–	–	–	4	–	32	–	–	–	–
Ga^{68} generators	–	1		0.5	–	2		11	–	–	–	–
I^{124}	–	–	–	–	–	–	–	–	10	–	65.8	–
I^{132} generators		76	–	1,220	–	72	–	720	–	71	–	1,480
I^{133}	–	3	–	60	–	1	–	20	–	1	–	20
K^{43}	19	–	16	–	20	–	10	–	19	1	9.1	0.1
Mg^{28}	–	172	–	24.5	1	203	0.05	34	2	169	0.1	25
Mo^{99}	–	23	–	2,210	–	18	–	1,620	–	15	–	1,010
Sr^{87m} generators	–	1	–	1	–	5	–	5	–	–	–	–
Tc^{99m} generators	–	116	–	11,450	–	27	–	2,650	–	20	–	2,000
Te^{129m}		–	–	–	–	–	–	–	–	1	–	1
Te^{132}	–	7	–	70	–	8	–	81	–	–	–	–
Xe^{128}	–	1	–	0.02[b]	–	1	–	0.02[b]	–	–	–	–
Y^{90} beads	–	4	–	65	–	12	–	492[c]	–	60	–	2,233[c]
Y^{90} generators	–	3	–	250	–	3	–	300	–	9	–	1,000

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

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

[c]Not mC, but number of individual beads (see Figure 19); activity per bead controlled by length of irradiation requested by customer.

28% decrease in demand for Mg^{28} was more than offset by the burgeoning increase in demand for Tc^{99m}. This increase is partly due to the development at BNL of a method for incorporating Tc^{99m} in a colloid which has permitted outstanding improvement in external visualization of organs such as the liver. Requirements for high-purity carrier-free Mo^{99} led to the successful development of a process for removing traces of radioactive I, Ru, and Te.

Applied Mathematics

The Applied Mathematics Department fulfils an important and continuing set of responsibilities to the entire Laboratory. These are to promote the researches of the Laboratory through the acquisition and maintenance of an appropriate complement of computing machinery, to provide continued programming support in the constantly evolving application of computers to research, to advise members of other departments on the mathematical formulation of problems for computers and the feasibility and necessity of computers for various novel applications, and to conduct a research program in the related areas of mathematics and mathematical physics, with special emphasis on the use of computers.

CENTRAL COMPUTING FACILITY

Systems and Utility Programs

No additions to the Central Computing Facility have been made during the past fiscal year, and the complement of equipment described in last year's report remains unchanged. Briefly, this consists of a 4-channel, 16-tape IBM 7094 system with two IBM 1401's, a CDC 924 system, and a small CALCOMP plotter. In addition, the Merlin computer, constructed by the Instrumentation Division, is administered by the Department. The capacity of the commercially acquired computers has now been effectively saturated. However, demands on this equipment continue to increase, and plans for the next two fiscal years must involve its expansion and elaboration. These plans have been submitted to the Atomic Energy Commission for approval.

The increase in the use of the IBM 7094 can be seen in Figure 1. In interpreting this figure, it is important to note two facts. First, the 1401's are not in themselves independent computers; they merely serve as peripheral processors for the 7094. To a large extent this is also true of the CDC 924. The latter, however, is increasingly used for a variety of small, independent problems for which it is more economical than the IBM 7094. Second, the hours of use indicated in the histogram are "clocked" research use and do not include maintenance time, programming training, or updating of the subroutine library, nor is service time due to machine malfunction taken into account. In view of these desiderata, it is unrealistic to assume that >1800 usable hours will be available per quarter. Thus, the 1650 hours used in the last quarter of fiscal 1964, considered together with the obvious gradient, indicate a saturation of the facility in the uncomfortably near future. This saturation is imminent in spite of a complete revision of the Brookhaven Operating System for the 7094. In this revision particular attention was paid to the more efficient buffering of input and output, a problem of special importance at Brookhaven National Laboratory.

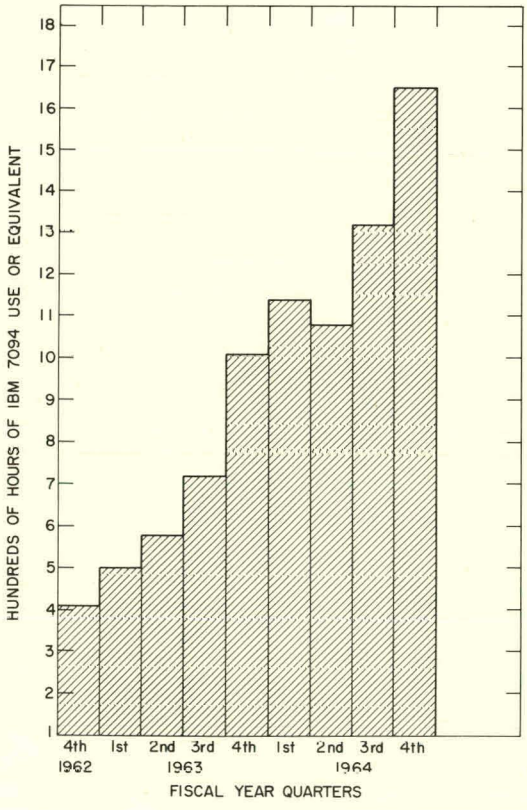


Figure 1. A histogram of central computer usage at Brookhaven National Laboratory.

SUPPORTING ACTIVITIES

Computer and Programming Research

The Engineering Group of the Department has completed construction of the optical spark-chamber film reader designed last year (Figure 2). This work was done in collaboration with a group from the Physics Department and with the aid of personnel from the Instrumentation and Mechanical Engineering Divisions. In addition, the programs for processing the output of this device were completed, and the entire complex constituted an operating system at the close of the year. In the interest of efficiency, a "preselector" was added to the system. This allows an operator to reject film that contains no "events of interest" and speeds up the over-all operation of the system. This reader is being used with the associated 7094 programs in the analysis of a 200,000-photograph $K^{\pm}$-p scattering experiment.

In cooperation with the Cosmotron Division, a cathode-ray-tube photograph reader has been designed for installation as an integral part of the CDC 924 computer. To minimize hardware construction and expense, the design emphasis is on the use of programming techniques and the computer's own hardware. The resulting reader will be sufficiently precise to be used for many spark-chamber experiments.

In a different direction, members of the staff were heavily involved in a continuing joint project with the Chemistry Department and the Solid State Group of the Physics Department to design a computer control system for several neutron diffractometers to be used at the new High Flux Beam Research Reactor. Instrumentation Division personnel also collaborated. The project involves the installation of a small computer for program control of several diffractometers and the preparation of the appropriate programs, so that several experiments may be run simultaneously.

The Sigma Center of the Nuclear Engineering Department maintains a library of $\approx$500,000 multientry items describing experimental neutron cross section data; this library's current rate of growth is 200,000 items/yr. To keep the library orderly and usable, automatic filing and retrieval methods must be used. A Sigma Center informa-

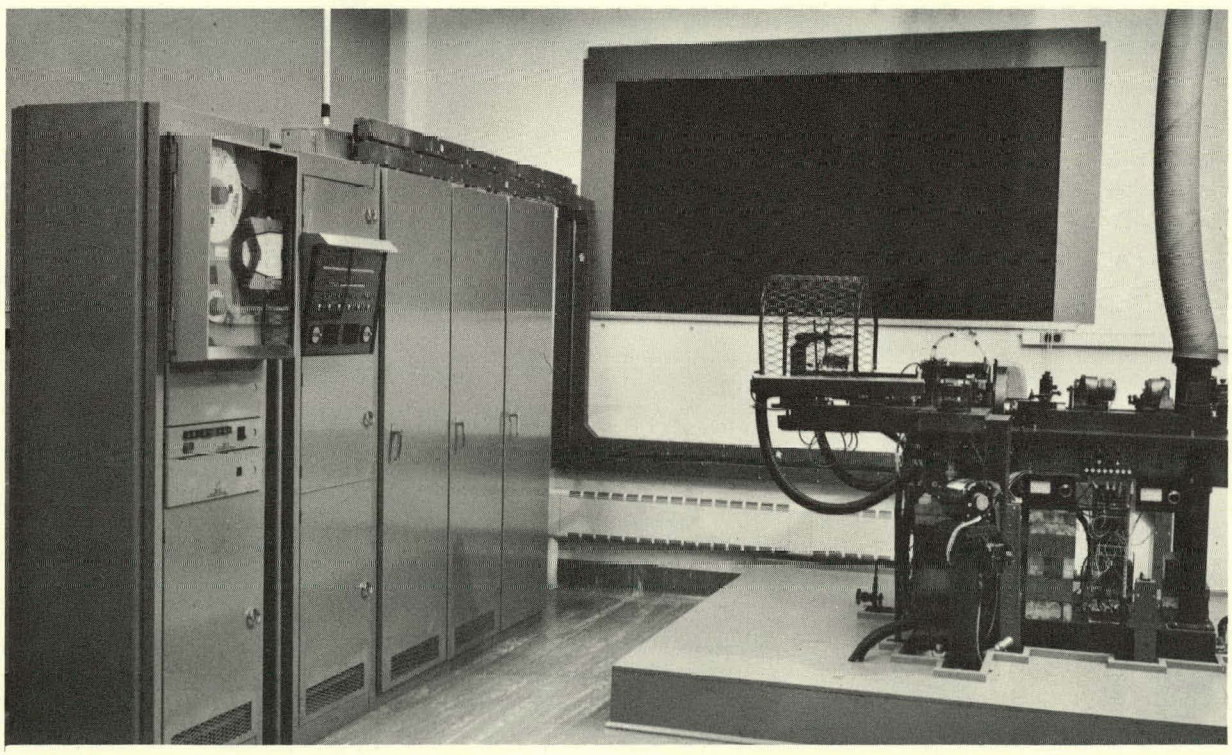


Figure 2. Optical film reader. The film handler and optical system are on the right. Electronics racks and the magnetic tape handler are on the left.

tion storage and retrieval system based on magnetic tape files has been prepared by this Department for use on the IBM 7094. The system is designed to make the Center's present files of information more readily accessible and, in particular, to allow rapid mechanized encoding of data from automatic measuring devices.

The preceding exemplify some long-term cooperative projects. Besides well-defined collaborative efforts such as these, there is continuous informal interaction between members of the Department and other researchers at the Laboratory concerning proper applications of computer equipment and techniques to the program of the entire Laboratory.

APPLIED MATHEMATICS RESEARCH

Included under this heading are research programs explicitly initiated and carried out by Department personnel. However, even this distinction is a mere convention, since much of the work is directly inspired by the Laboratory's program, and all of it is directed toward those scientific areas of particular interest to the Laboratory.

Differential and Integral Equations

Work continued on the problem of locating brain tumors by a technique involving the ingestion by the patient of radioactive material which is preferentially absorbed by the tumor. However, retrieval of the pertinent information by observation of the decay from counters arranged around the patient's head presents a formidable mathematical problem. The solution clearly lies in a fundamental mathematical theorem which gives the point-value of a function on a circle in terms of an equation involving the integral of the function over chords. Because of imperfect collimation, background noise, the obvious necessity for a finite number of counters, etc., the necessary numerical implementation of this approach requires a considerable amount of "mathematical experimentation" with a computer. Figure 3 is an example of the results obtained. It should be noted that this project is a prime example of a very common occurrence: a purely mathematical problem of great intrinsic interest simultaneously has an important practical application.

Research has been carried out on generalized eigenfunction expansions associated with linear

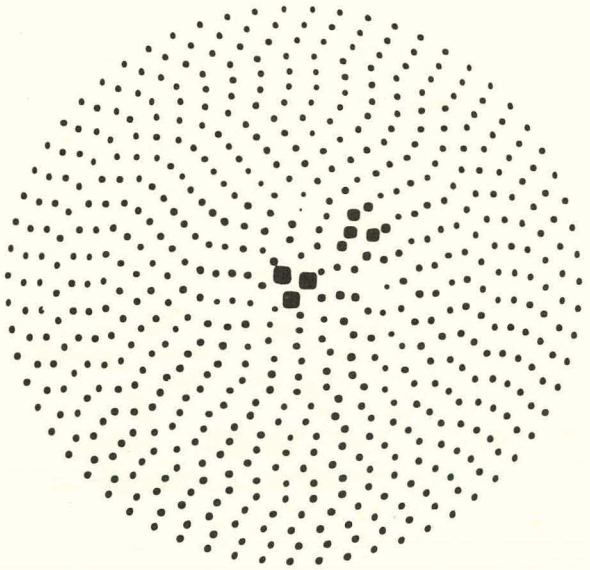


Figure 3. The spatial distribution of radioactive material, recovered from coincidence counter data. This computer-generated display shows two concentrations of radioactive material, one at the center and the other above and to the right of the center. The numerical data show a much greater contrast than can be depicted by this method of indicating concentration by spot size.

transformations possessing an absolutely multiple continuous spectrum. In this way a clearer understanding has been gained of previous results on singular integral operators. This work is part of a continuing general investigation of the continuous spectra possessed by some linear operators.

Research was conducted on the differential equations that describe heat flow problems. Of primary interest was the question of calculating the temperature patterns in a conductor for certain kinds of conditions given at the boundary of the conductor. For example, if the temperature distribution at the edge of a thin metal plate is prescribed and maintained for a long time, then the steady-state temperature at any point inside the plate can be calculated approximately by either of the two methods developed and reported last year. Methods were also developed for treating some unsteady-state heat flow problems.

In cooperation with members of the Biology Department, a theoretical method for handling enzyme kinetics was studied. The method consists of utilizing the experimental data in such a way as to arrive at numerical values that are useful in explaining enzyme reactions. The method was studied with the aid of the computer, and the re-

sults of the study are currently being applied to experimental data.

Programmed Pattern Recognition

As indicated in previous reports, an extensive program is directed toward eliminating the need for detailed human intervention in the initial scanning phase of processing bubble-chamber film. The quantity of data output by the Laboratory's flying-spot digitizer (FSD) for each picture is rather large, and the first task of an automatic scanning program is to reduce it to a more manageable form. Moreover, the economics of bubble-chamber data processing imposes rather stringent requirements on the speed at which this data reduction must be carried out. This problem has been solved by the development of an IBM 7094 program which, using special coding techniques, associates most of the input data into individual particle tracks and produces a description of each of the reconstructed tracks in terms of suitable parameters. The program is designed to operate serially on the input data, at an over-all rate comparable with the data rate of the FSD. As the second stage of processing, it is necessary to include a track-editing program to check the spurious tracks in the output of the track reconstruction program and link possibly incomplete segments together into complete tracks. A third, vertex-finding stage may then attempt rudimentary scanning operations that result in the listing of all possible vertex candidates recognizable in a single stereo view. Prototype versions of both track-editing and vertex-finding were completed in fiscal 1964 and tested by using Brookhaven and CERN FSD data.

Present plans call for the merging of all three stages into a single program whose output will be a summary of each picture in terms of vertex candidates, precision coordinates of associated tracks, fiducial locations, and certain over-all statistics associated with the energy and intensity of the beam. This output will be collected on magnetic tape and used for the selection of specified types of physical events.

Mathematical Physics

A few years ago Regge showed that, in non-realistic potential theory, the high energy behavior of scattering amplitudes in the crossed channel is closely related to the bound-state solutions of the corresponding Schrödinger equation. Recently, field theoretical extensions of Regge's analysis have been achieved by several groups, either from S-matrix theory based on the assumption of the validity of the Mandelstam representation, or from the off-the-mass-shell theory based on the Bethe-Salpeter formalism. In the latter approach, Bertocchi, Fubini, and Tonin have shown, within the framework of the multiperipheral model, that the leading asymptotic behavior of the scattering amplitudes is determined by a homogeneous equation equivalent to the partial-wave Bethe-Salpeter equation. A result equivalent to that obtained by Bertocchi et al., which, however, is independent of the approximations used by these authors, has been obtained via the use of the perturbation theoretical integral representation. In particular, the connection between the high energy behavior of the scattering amplitude and the analyticity in the complex angular momentum plane has been clarified in this work. Furthermore, it was shown that other types of non-Regge behavior become possible in the high energy limit. Work related to the question of subtractions in the perturbation theoretical integral representation has also been done.

It has also been shown that an SU_3 symmetry analogous to that for I-spin and hypercharge in strong interactions may exist also for ordinary spin and baryon number.

Informal courses taught by members of the Department have included the topics of programming, numerical analysis, and Monte Carlo methods and have drawn participants from many departments of the Laboratory. In addition, an Applied Mathematics Department Seminar was initiated this year; distinguished visitors and local scientists have contributed to a stimulating series of lectures on applied mathematics and computational methods. These, too, have drawn part of their audience from interested members of the entire Laboratory.

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

LIFE SCIENCES

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

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 *Subunit Structure of Proteins*, was attended by 250 scientists in addition to members of the Brookhaven laboratory staff and will be published as the 17th volume in the Brookhaven Symposia series.

A major addition to the Biology Building is in the process of construction and will add ≈33,000 sq ft of laboratory and special facility space. The addition is specifically for expansion in the plant sciences and will provide extensive controlled growth chambers, as well as several shielded rooms for growing plants under controlled conditions in the presence of various levels of ionizing radiation. Completion is scheduled for April 1965.

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

ANIMAL PHYSIOLOGY

Radiation-Induced Aging

Radiation causes a decrease in the life expectancy of animals which closely resembles the natural aging process. A study of both natural and radiation-induced aging is being undertaken to determine the causes of each. It has been postulated that aging results from the accumulation of viable mutations in the somatic cells of the body. This theory gains support from the fact that radiation both shortens the life-span and is a patent mutagenic agent. A quantitative evaluation of the theory requires a measure of the mutation frequency in somatic cells. Chromosome aberrations in liver cells have been assumed to be proportional to such mutations. The following correlations have been established: (1) Aberrations increase linearly with age in normal animals, and as many as 80% of all cells may show aberrations in old animals. (2) After x-irradiation, the aberrations increase strikingly and are eliminated slowly over a period of months. (3) With chronic gamma irradiation, both the increase in chromosome aberrations and the life shortening are only ≈2.5% of that produced by an equal dose administered acutely. (4) Acute neutron irradiation causes a rapid and sustained increase in aberrations. (5) Chronic neutron irradiation causes as much chromosome damage and as much life shortening as an equal dose given acutely. (6) Normal mice of a long-lived strain develop chromosome aberrations at a much slower rate than do mice of a short-lived strain.

Thus it appears that aging results from an instability in the chromosome structure of somatic cells. Experiments in progress are designed to assess the factors responsible for chromosome stability. Present results indicate that in tissues in which cells divide often, aberrations are eliminated by cell selection; in tissues with nondividing cells the chromosomes exhibit a remarkable degree of repair. Small chromosome irregularities are repaired in minutes or hours; more severe aberrations can be healed over a period of months, provided that the cell is not required to undergo cell division. Very severe damage such as that caused by neutrons can not be repaired.

Effects of X-Rays on Ion Transport in Erythrocytes

Irradiation is known to induce loss of potassium and gain of sodium in a variety of animal cells. This interference with ion transport was studied in human erythrocytes *in vitro*. The findings indicate

inactivation by radiation of the potassium- and metabolism-dependent process concerned with removal of sodium from the cell. In the erythrocyte, as in other cells, functional activity is considered to be coupled with hydrolysis of adenosine triphosphate (ATP), which represents stored energy derived from metabolism. The erythrocyte membrane hydrolyzes ATP, and two components appear to be involved. One requires magnesium ions, but not sodium and potassium, and is not inhibited by certain glycosides that interfere with ion transport. The other requires all the ions and is inhibited by the glycosides. This component is considered to be involved in the system that removes sodium from cells. Inhibition of this form of ATPase activity was found to parallel the inhibition of sodium efflux from the cells. The levels of ATP and metabolism in the cells were not affected by irradiation that depressed transport and the ATPase activity. It appears, therefore, that the effect of radiation on ion transport is attributable to action at the cell membrane.

Fate of H^3-Thymidine in the Marmoset

Administration of tritium-labeled thymidine with subsequent autoradiographic estimation of the radioactive tritium in cell nuclei is used for study of deoxyribonucleic acid (DNA) synthesis and other aspects of the kinetics of cell replication. The thymidine is a precursor of DNA. It is generally assumed that any method of administration results in "pulse labeling" of DNA, i.e., the thymidine is available to cells for a relatively short period of time. As a preliminary to study of the kinetics of cell formation in the oral mucosa of the marmoset, tests were made for labeled thymidine in blood plasma following intravenous, intraperitoneal, and intramuscular administration of the precursor. With intravenous injection the thymidine in plasma was maintained briefly at a high level, which fulfilled the conditions for pulse labeling. With the other methods of administration the precursor was present in plasma at lower levels for relatively long periods of time, >1 hr with intramuscular injection. Thus, these methods are not suitable for pulse labeling. About 1% of the administered thymidine was estimated to be incorporated into DNA; the remainder was degraded. It has been assumed that the major fraction of the tritium-labeled degradation products is represented by water and that the nonvolatile labeled material in plasma represents thymidine. However, the proportion of thymidine in the nonvolatile material was found to decrease rapidly with time after administration.

DNA Synthesis in Cells of the Mouse Mammary Gland

By appropriate administration of the DNA precursor thymidine labeled with radioactive hydrogen or carbon and subsequent estimation of the radioactive elements in cell nuclei by autoradiography, the kinetics of DNA synthesis and cell proliferation may be studied. This procedure has been used in examining the effect of ovarian hormones on DNA synthesis in the mouse mammary gland. In controls the duration of synthesis in alveolar cells varied from 15 to 28 hr. In ovariectomized animals treated with 17-β-estradiol and progesterone the time of synthesis was shorter and less variable, 10 to 12 hr. Markedly different amounts of the administered hormones shortened the period of synthesis to the same extent. Other cell types in the gland were affected by hormone administration in the same way as the alveolar cells. The differences in duration and variability of the synthetic time between the controls and experimental animals presumably reflect cyclic and limited hormone levels provided by ovarian secretion in the controls and the relatively high and constant levels in the other animals. In each type of cell the duration of synthesis appears to have a characteristic minimum value under hormone treatment. Conceivably, the hormones may affect the rate of nucleic acid synthesis or may synchronize chromosome duplication. It has been proposed that in general the duration of DNA synthesis does not depend upon the rate of cell proliferation. However, in the mammary gland at least it appears that the synthesis varies with proliferation.

Action of Insulin on Liver

Glucose-C^{14} infusion experiments in which biopsy samples of liver tissue were collected and analyzed for glycogen content and for the amount of C^{14} contained in liver glycogen have allowed further clarification of the effect of insulin on glucose production by the liver and glucose utilization by the tissues. In the period from 18 to 23 hr after the last meal the dog has a steadily diminishing liver glycogen content. The uptake of blood glucose-C^{14} by liver at this time is quite small, and the incorporation of blood glucose-C^{14} into liver

glycogen is practically nil. However, when insulin is given intravenously, accompanied by just enough glucose to prevent the usual fall in blood glucose concentration, several effects on liver are seen. In the first hour of insulin infusion the steady decline in liver glycogen content is interrupted; however, during this time there is little increase in the amount of blood glucose-C^{14} incorporated into glycogen. Continued infusion of insulin beyond this time results in an increase in the incorporation of blood glucose-C^{14} into glycogen which in the third and fourth hours of insulin infusion becomes very large. Little or no further change in total liver glycogen content accompanies this incorporation of blood glucose-C^{14} into glycogen. At all periods the insulin infusion increases the uptake of glucose from the blood by the rest of the body (other than liver). The uptake of glucose by the liver itself, for glycogen synthesis, which is seen in the third and fourth hours of insulin infusion may represent as much as ⅙th of the total blood glucose uptake of the whole body; prior to insulin and during the early period of insulin infusion, blood glucose uptake by the liver is quite small. The effects of insulin on the liver are then (1) to inhibit glycogen breakdown and glucose production, and (2) to enhance glycogen synthesis from blood glucose. These two effects appear to have different causal mechanisms.

Differences in the Amino Acid Composition of Antibodies

Previous investigations have indicated no differences in the structure of antibodies which would account for their specificity, that is, their ability to react only with homologous antigen. However, by the use of improved analytical procedures, significant differences were detected in the amino acid composition of certain rabbit antibodies. The antibody directed against a negatively charged haptenic group had the higher arginine and isoleucine content, while the antibody directed against a positively charged hapten had the higher aspartic acid and leucine content. The levels of the other amino acids were strikingly similar. The purity of the preparations, established with radioactive reagents, showed that negligible contamination occurred during the isolation of the antibodies and that the activities of the final products were practically 100%.

These results suggest that antibody synthesis is under genetic control and that the observed differences represent changes in the amino acid residues at or near the active site. However, proof of this interpretation depends on the demonstration that the differences do not merely represent pools of different gamma globulin molecules in which the antibody activities are segregated. This possibility was minimized by isolating both antibodies from individual rabbits which were homozygous with respect to their globulin production and finding the same differences in amino acid composition. Further evidence for the interpretation was recently obtained from the amino acid analyses of a third rabbit antibody directed against an uncharged haptenic group. This antibody differed from the others in tyrosine, aspartic acid, and serine content, which again demonstrates a unique amino acid composition for an antibody.

GENETICS

Relative Biological Efficiency of Ionizing Radiations

Studies comparing the relative biological efficiency (RBE) of different types of ionizing radia-

Table 1

Comparison of the Amino Acid Compositions of Three Rabbit Antibodies

Amino acid residue	Antibody directed against: Positively charged hapten	Negatively charged hapten	Uncharged hapten
	Moles residue/mole antibody		
Lysine	69.4	69.6	70.8
Histidine	16.6	16.5	16.9
Arginine	**42.5**	44.6	44.6
Aspartic acid	**110**	**106**	**112**
Threonine	162	162	163
Serine	149	150	**143**
Glutanic acid	123	122	121
Proline	110	110	110
Glycine	110	109	109
Alanine	81.4	79.8	77.3
Valine	128	128	129
Methionine	13.5	13.8	13.6
Isoleucine	**46.4**	48.8	48.3
Leucine	**91**	89	89
Tyrosine	56.2	56.2	**50.9**
Phenylalanine	44.9	44.3	44.5

The boldface amino acid contents for a given antibody differ significantly from the corresponding contents for the others. The differences are considered the basis for antibody specificity.

tion were carried out by using the Yg_2/yg_2 genotype in maize. Seeds of this genetic stock were irradiated. When loss of the Yg_2 allele occurs because of chromosome breakage, a yellowish (yg_2) streak appears in the seedling leaves. The frequency of such streaks was used as a quantitative measure of radiation damage. The effectiveness in breaking chromosomes with monoenergetic fast neutrons (0.43, 0.65, 1.0, 1.5, and 1.8-MeV) was compared with that of 250-kVp x rays. RBE values, calculated from the relative slopes of linear regression lines for neutrons and x rays, averaged 78 in one experiment and 68 in another. Neutrons of 0.43 MeV were the most efficient of the neutron energies tested. The average yg_2 "mutation" rate per krad for x rays was calculated to be 10.2×10^{-4}, and that for neutrons (1.0 and 1.5-MeV), 576×10^{-4}. The amount of energy absorbed in the chromosome arm, on which Yg_2 is located, to induce a break was estimated to be 0.22×10^{-3} ergs of x rays and 0.39×10^{-5} ergs of fast neutrons.

Maize seeds of the same Yg_2/yg_2 genotype were also irradiated with $\simeq$8-BeV π^- mesons and $\simeq$7-BeV muons from the Alternating Gradient Synchrotron at Brookhaven. Compared to 250-kVp x rays, the RBE for π^- mesons was found to be $\simeq$3.2, and that for muons, $\simeq$0.8.

Studies are now being directed toward determining the energies absorbed by the nucleus, chromosome, and chromosome arm in order to cause chromosome breakage, growth inhibition, and lethality with radiations of different linear energy transfer.

The Genetics Map in *Salmonella*

The genetic linkage map of *Salmonella typhimurium*, which has been primarily worked out in this laboratory, contains >130 gene loci. A similar map of *Escherichia coli*, prepared in other laboratories, contains a similar number of loci. Comparative study of these maps reveals complete homology between the two genera of bacteria with regard to the positions and functions of comparable genes on their chromosomes. This observed high homology is a very unexpected feature, since in higher organisms chromosomal rearrangements are observed as the first step in evolutionary differentiation. A possible explanation for this phenomenon comes from the information accumulated during a number of years: In *S. typhimurium* gene loci are not distributed at random along the chromosome, but genes controlling related functions are often clustered together. Fourteen groups of phenotypically different mutants, representing 87 loci, have been analyzed. Of these, 63 (72.4%) occur in 17 functionally similar clusters which are scattered throughout the genome. Where there is a mechanism capable of dispersing the genes of a cluster, as exists in bacteria, they should, given sufficient time, become randomly distributed throughout a genome. If a cluster is to persist, therefore, the gene arrangement it represents must give some selective advantage to the organism. Consequently, chromosomal rearrangements that would disturb clusters would be detrimental and selected against.

Transduction experiments with *S. typhimurium* × *E. coli* hybrids show that the *Salmonella* phage P22 is able to transport fragments derived from either *Salmonella* or *E. coli* chromosomes. Integration of *E. coli* genetic material into *Salmonella* chromosomes, however, occurs with a frequency which is <1% of the frequency of integration of *Salmonella* material. Evidence indicates that this failure of integration is due to a lack of homology at the subgenic level. Thus the evidence suggests that between *S. typhimurium* and *E. coli* a high degree of homology exists with respect to gross structure of the genome, but a low degree with respect to fine structure. This divergence in homology may originate through changes within coding triplets that, because the code is degenerate, do not affect transcription.

Genetic Transformation in Bacteria

The mechanism of entry of transforming DNA into pneumococcus, the molecular fate of this material within recipient cells, and the integration of its genetic information with that of the cells are under study. Earlier work revealed that the initially double-stranded transforming DNA shortly after entry is present as single strands and fragments, inorganic phosphate, a sugar phosphate, and 5′-deoxyribonucleotides. This suggests involvement during entry of a deoxyribonuclease which cleaves the 3′-deoxyribose phosphate linkages in one strand of the DNA. Therefore the deoxyribonucleases of pneumococcus are being fractionated and tested to see whether any has the appropriate specificity. The single-stranded DNA arising during entry of the transforming material presumably bears the genetic information. Integration of this information with that of the recipient cell is being considered in terms of a genetic analysis of some

66 different mutations at the amylomaltose locus. For this purpose experimental procedures were established for suitably reproducible measurement of the frequency of integration of marker from wild-type DNA and frequency of recombination between mutants to give the wild type. Results to date indicate that the frequency of transformation of a single-site mutant by wild-type DNA is characteristic of the mutation and can vary 20-fold; the frequency of recombination between two mutant sites increases with the distance between the sites determined by means of overlapping "deletions"; and the frequency of recombination depends upon the frequency of integration of wild-type marker corresponding to a recipient mutation but not upon the frequency of integration of donor mutation. These findings, although preliminary, provide a first step toward formulation of a model for genetic recombination in transformation.

Cooperative Radiation Mutation Program

The facilities at Brookhaven National Laboratory are used to irradiate seeds, cultures, and whole plants in attempts to induce beneficial mutations. Plant breeders and cytogeneticists provide the plants and seeds and are responsible for culturing the irradiated material and screening for mutations.

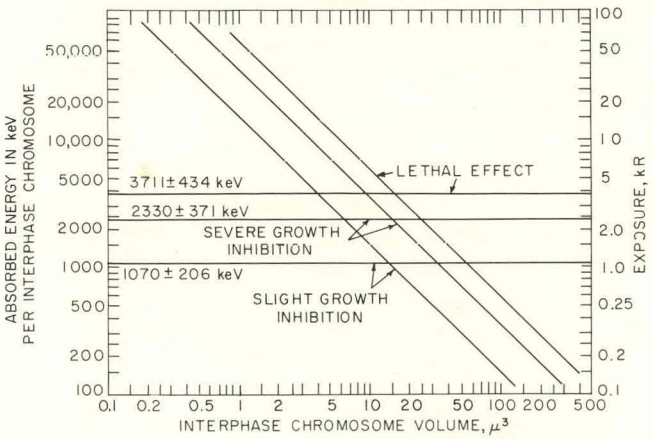


Figure 1. Chromosomes and radiosensitivity in plants. The relationship pictured derives from study of a series of herbaceous plants. For each effect of radiation the dose, expressed as kR, is linearly related to the average volume occupied per interphase chromosome. Thus, the radiosensitivity of each plant in the series is determined by its average chromosome volume. This volume in turn determines the energy absorbed per chromosome. As indicated, roughly the same energy absorption per chromosome produces the same degree of effect in all the plants. The energy absorption per chromosome required for a given effect in woody plants is ≈½ that in herbaceous plants.

I. Forbes Jr., of the Georgia Coastal Plain Experiment Station, Tifton, Ga., reports that the relative effectiveness of thermal neutrons and x rays in producing mutations varies according to the genetic locus or change considered. He studied the frequency in Blanco blue lupine of the mutations, big cotyledon, brilliant yellow, white plumule, and yellow-green. For production of big cotyledon and yellow-green, x rays and thermal neutrons were equally effective. However, neutrons were 3 times as effective as x rays in producing brilliant yellow and 6 times as effective in the case of white plumule.

G.W. Burton and D.K. Ourecky, also of the Georgia Coastal Plain Experiment Station, suggest that thermal neutrons and ethylmethane sulfonate are not always effective in achieving variability in *Pennisetum glaucum*. For 1 of the 6 characteristics studied, plant height, they state, "On the average, 30 minutes of thermal neutrons and 0.2% solution of ethylmethane sulfonate did not significantly reduce plant height. The heavier dosages did significantly reduce plant height and the greatest reduction was observed in plants from seeds treated with thermal neutrons for 90 minutes. This treatment reduced plant height about 7 inches, on the average. It is interesting that inbred 34 was not reduced in height by any thermal neutron treatment but was significantly reduced with ethylmethane sulfonate treatments. On the other hand, inbreds 13, 27 and 239 were reduced in height by thermal neutron treatment but were not affected by ethylmethane sulfonate treatments."

A.L. Anderson of Michigan State University reports the release of a new bean variety called Gratiot which displays greater disease resistance than the previously released Sanilac and Seaway varieties. R.P. Pfiefer and R.D. Schein of Pennsylvania State University Agricultural Experiment Station report a new barley variety, Pennrad, which has the characteristic of better winter hardiness. This mutation was produced by thermal neutron treatment.

CELL PHYSIOLOGY

Radiosensitivity in Plants

It is clear that the responses of plants and other living systems to ionizing radiations are mainly

expressions of injury produced in chromosomes. A continuing study of radiation effects in plants has led to the theory that the radiosensitivity of a chromosome is directly proportional to its volume. This theory is sufficient to account for a number of phenomena: the difference between the sensitivities of individual members of a complement of chromosomes within a cell, the difference between the sensitivities of the same cell at various stages of its life cycle, and the difference between the sensitivities of plant species. In each instance the difference can be related to differences in chromosome volume. The sensitivity of a complement of chromosomes and thus of the cell and hence ultimately of the whole plant is some average of the sensitivities of individual chromosomes and is directly related to some average of the volumes of all chromosomes of a complement. In comparisons between plants, slight or severe growth inhibition or lethality serves to describe the sensitivity of the chromosome complement. Although the particular average of the volumes of the chromosomes that determines the sensitivity of the chromosome complement is not readily defined, it practically equals the directly determined average volume per chromosome, which in turn closely approximates the nuclear volume divided by the chromosome number. The interphase nuclear volume is readily determined in the apical shoot meristem.

Using the measures of sensitivity and approximation of average volume per chromosome indicated, further work was carried out on the effects

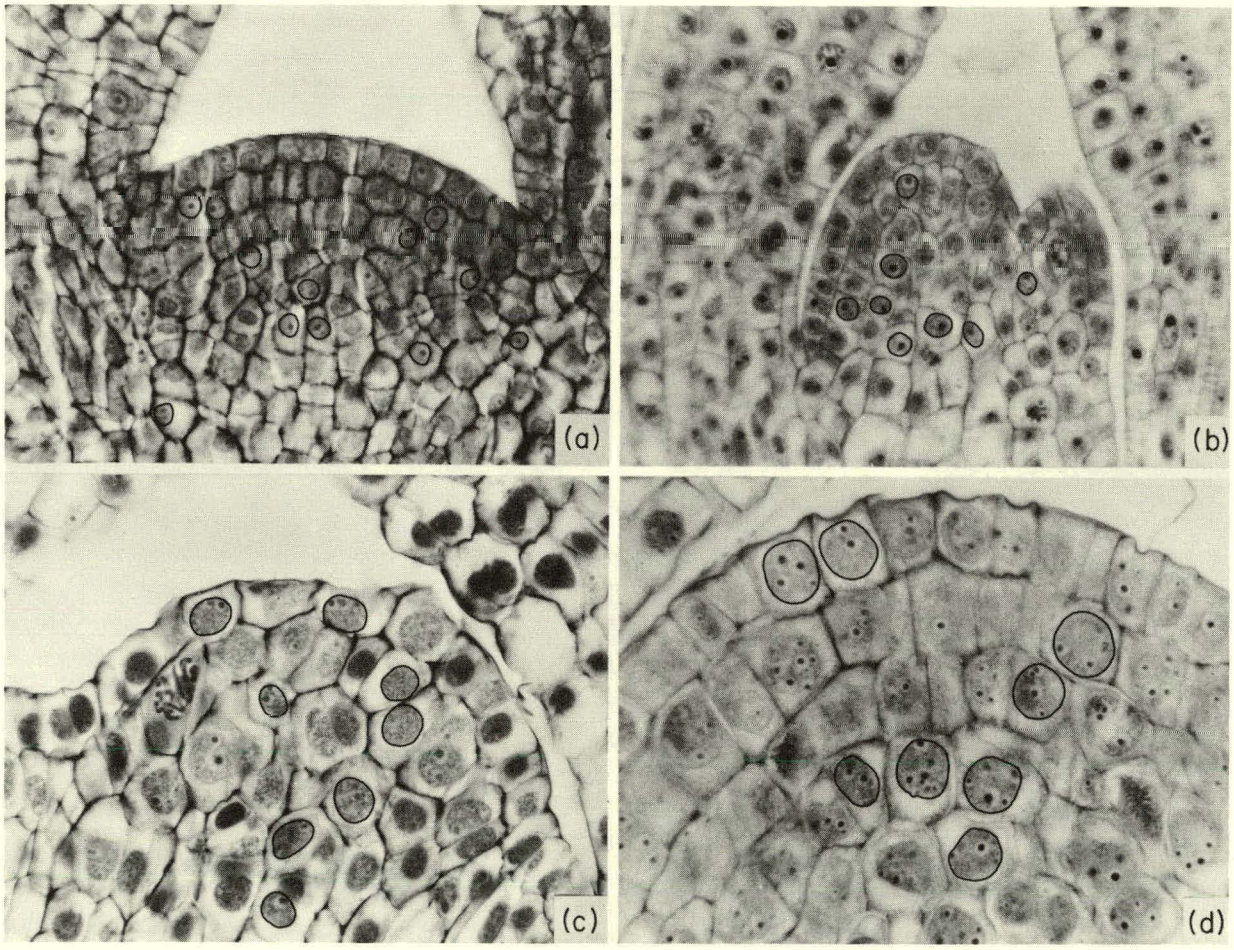


Figure 2. Interphase nuclei in apical meristems. Radiosensitivity in plants is a function of the average volume occupied per chromosome. This volume may be estimated from the volume of the nucleus at interphase divided by the number of chromosomes. The photographs of apical meristem cells of four plants illustrate the differences between plants in size of the nucleus. Interphase nuclei are outlined. The plants and respective chromosome numbers are (*a*) *Sedum*, 128; (*b*) *Luzula*, 6; (*c*) *Tradescantia*, 12; (*d*) *Chrysanthemum*, 198.

of acute and chronic x or gamma radiation on additional species of woody and herbaceous plants. For all end points of sensitivity used, with both kinds of exposure, both kinds of plants showed sensitivity directly proportional to average interphase chromosome volume. However, woody species exposed to acute irradiation were about twice as sensitive as herbaceous species having comparable interphase chromosome volumes. With chronic irradiation the woody plants tolerated $\approx$⅛th the daily exposure tolerated by the others. It is of interest that many gymnosperms and some angiosperms are killed by acute exposures between $\approx$600 and 1200 R, a range known to be lethal to many mammalian species. The reasons for the difference between the sensitivities of woody and herbaceous plants are not yet clear.

The role of chromosome volume in determining radiosensitivity becomes more understandable when energy absorption is considered. The larger the volume, the greater the amount of energy absorbed and damage effected during exposure to a given amount of radiation expressed in the usual roentgens or rads. However, when the exposure is calculated as average energy absorbed per chromosome it appears that in all herbaceous species $(3.7 \pm 0.4) \times 10^6$ eV produces a lethal effect, $(2.3 \pm 0.4) \times 10^6$ eV produces severe growth inhibition, and $(1.1 \pm 0.2) \times 10^6$ results in slight inhibition. For all woody species tested the corresponding values are $\approx$½ those given. It appears, therefore, that the genetic damage produced per unit of energy absorbed within the chromosomes is about the same for all chromosomes in all species within each of the two groups studied.

The Ultrastructure and Pigments of the Photomotor System of *Euglena*

Although *Euglena* has been a favored object for studies of phototaxis during the past century, relatively little is definitely known about the cellular basis of this phenomenon. Over the years the concept has developed that orientation to light is mediated by the shading effect of the eye spot upon the "real" photoreceptor which is located in the swelling of the flagellum, the paraflagellar body. This concept is based on inference from the behavior of strains of *Euglena* that appear to lack one or the other of these structures. Direct evidence that the so-called photoreceptor is pigmented or even an accurate absorption spectrum of the eye spot has been lacking.

Attempts to obtain highly purified eye-spot preparations have now proved successful. The relative freedom from contamination from other components has been assessed spectrophotometrically and by electron microscopy. The absorption spectrum of these granules matches the published action spectra for positive phototaxis exceptionally well. These observations suggest that the eye spot has a more direct role in phototaxis than is currently believed. The eye-spot pigments have been fractionated and identified.

The fine structure of the motor system has been studied in some detail. Two points are particularly worthy of note with regard to the problem of phototaxis. The eye spot is intimately associated with structural components of the motor system, specifically some of the fibers that pass from the blepharoplast of the emergent flagellum up along the reservoir and become associated with the pellicle. In addition, the so-called photoreceptor is only the lenticular portion of an intraflagellar complex which extends far out into the emergent flagellum. These observations indicate that the photomotor system of *Euglena* is more complex than has been assumed and may provide the basis for an explanation of the direct effect of light absorption by the eye spot in determining the flagellar activity or the form of this activity in *Euglena*, or both.

Photoperiodism and Development in Plants

Many plant processes are controlled by low energies of red ($\approx$660-mμ) and far-red ($\approx$730-mμ) light acting through the chromoprotein photoreceptor phytochrome. Low-noise spectrophotometric methods are being used to assay phytochrome, both *in vivo* and in extracts, in connection with various experimental systems in which physiological processes can be studied concurrently. In the growth of excised stem segments of etiolated *Pisum* plants, there is a striking disagreement between the state of phytochrome assayed spectrophotometrically and that indicated by physiological responses. Attempts to relate phytochrome transformations to anatomical, developmental, and photoperiodic characteristics of many other materials are also in progress. Methods of obtaining stable phytochrome in cell-free systems are being developed and directed towards reproducing

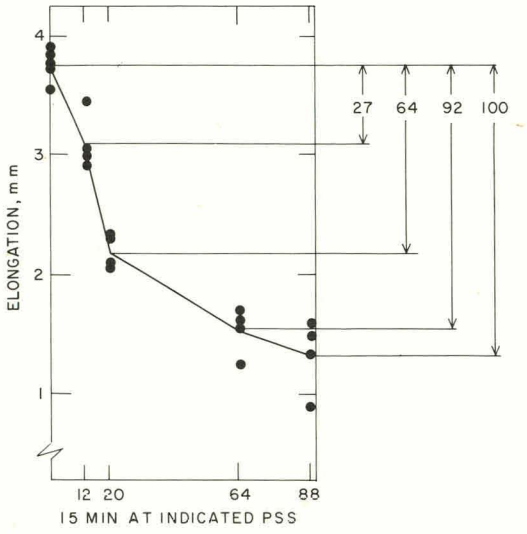


Figure 3. An experiment relating elongation in etiolated *Pisum* stem segments to the initial photostationary state (PSS) of phytochrome, that is, the percentage of the pigment in the far-red-absorbing form. Segments were initially 4.5 mm long. Growth was for 20 hr in darkness after the initial light exposure. Each point is the mean of 10 segments. The apparently simple relationship here illustrated is profoundly modified under other conditions.

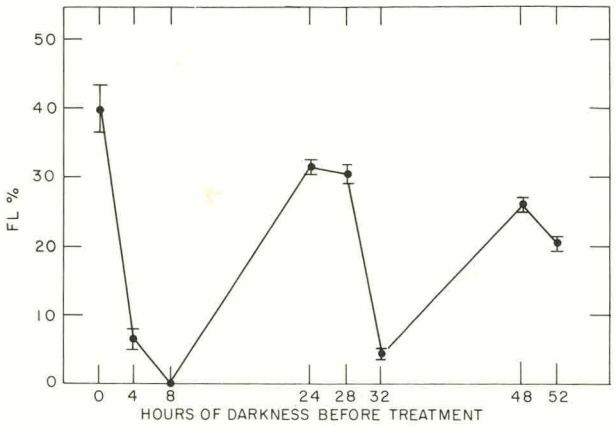


Figure 4. An experiment indicating the participation of an endogenous circadian rhythm in the photoperiodic response of *Lemna perpusilla* grown in axenic culture with minerals, sucrose, and ethylenediaminetetraacetic acid. Percentage of flowering (FL %) is plotted as a function of the length of a dark period preceding exposure of all cultures to 7 repetitions of the schedule: ¼ hr of light and 13 hr of darkness; ¼ hr of light and 10½ hr of darkness.

in such systems the phytochrome transformations so far observed only *in vivo*. Finally, the role of endogenous circadian rhythms in the flowering of *Lemna perpusilla* is under detailed study in an attempt to understand the relationship of phytochrome, as the photoreceptor, to the basic timing mechanism in photoperiodism.

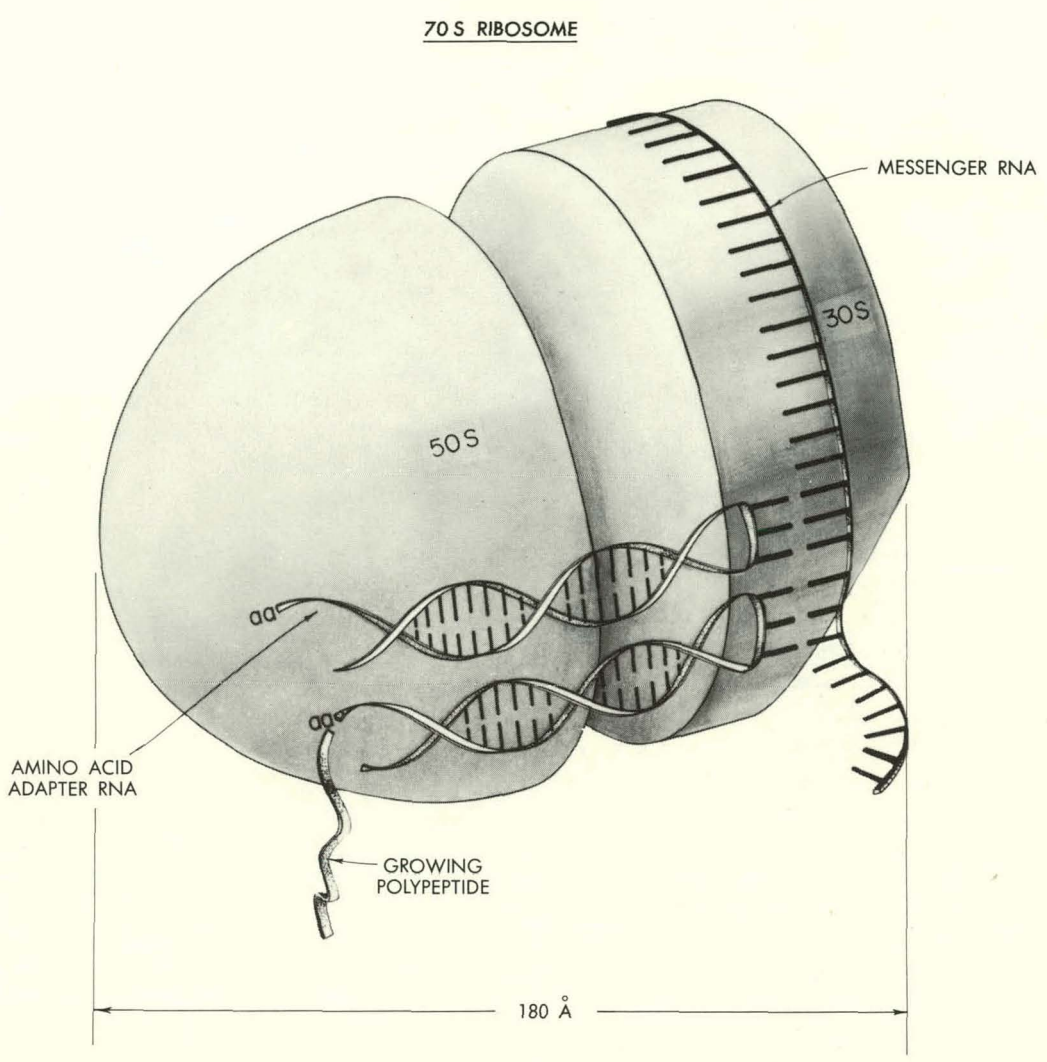
Morphogenesis in Plants

New cells, tissues, and organs of plants develop from meristematic tissues. If these meristematic cells are in any way changed by chemical and physical means, the whole course of plant development is also affected. The excised shoot apex of the fern *Osmunda claytoniana* L. grown under controlled conditions of sterile nutrient culture and irradiated with a 25-μ deuteron microbeam at a threshold dose of 127,000 rads was examined at 2 levels of organization. At the macromorphogenetic level the irradiated apex exhibited no change in leaf development, no interfoliar growth centers, and no disturbance in phyllotactic patterns. At the tissue level of organization the following were observed: development of a radiogenic lesion in the path of the microbeam within three weeks postirradiation; confinement of the radiogenic lesion to within the promeristem apical initial cells and a few of the cells of the pith mother cell zone; a wound response to the microbeam that develops peripherally to the radiogenic lesion; development of a new, isolated, and organized growth center from normal promeristem cells adjacent to the area of the wound response; and production of incipient vascular tissue together with a new pith mother cell zone in association with the new center of growth.

At a still lower level of organization and activity, i.e., DNA synthesis, it was found that 127 krads from the 25-μ deuteron microbeam reduced DNA synthesis in the prismatic layer and subjacent regions of the cultured meristem complex ($\approx$500 $\times 10^6$ μ^3 of tissue) by 50 to 80% immediately after treatment. Studies of DNA synthesis recovery are under way to help gain a better understanding of the events observed at histological and macromorphogenetic structural levels.

Mechanism of Protein Synthesis

Ribosomes are considered of central importance in the manufacture of all proteins. Ribosomes from the bacterium *Escherichia coli* can be reversibly dissociated into two ribonucleoprotein subunits, a 30 S and a 50 S subunit with molecular weights of $\approx 0.7 \times 10^6$ and 1.8×10^6, respectively. Protein synthesis requires the presence of both the 30 and 50 S subunits and attachment to the ribosome of



messenger ribonucleic acid (RNA), the template of protein synthesis. Earlier suggestion that messenger RNA binds exclusively to the 30 S ribosomal subunit was strongly supported by studies of binding between ribosomes and synthetic polyribonucleotides. In particular, polyribouridylic acid (poly U), the synthetic messenger RNA for polyphenylalanine synthesis, was found to bind strongly to either the 70 S ribosome or its 30 S subunit, but little or not at all to the 50 S subunit. Optimum interaction between ribosomes and poly U occurs in 5 m*M* Mg^{++} with the formation of complexes containing one poly U molecule and one or more ribosomes. The lower the ratio of poly U to ribosomes the larger the average aggregate size; these aggregates are called polysomes.

It seems likely that the ribosomal site to which the messenger RNA attaches is well defined with

Figure 5. A model for the role of the ribosome in protein synthesis. Messenger RNA and adapter RNA are believed to interact at the surface of the 70 S ribosome. Their coding units are indicated by the short straight projections from the main chain. Messenger RNA is a single polynucleotide chain; adapter RNA is probably a double helix with irregular base-pairing except for the exposed coding units. The growing tip of the protein is attached to an adapter RNA, which in turn is bound to a specific site on the messenger RNA template. An amino acid–adapter RNA complex is adsorbed at an adjacent specific site on the messenger RNA template, which results in the addition of an amino acid to the growing protein. Peptide bond formation is believed to be mediated by an enzyme called protein synthetase. The ribosome provides a stabilizing surface for maintaining messenger RNA in an active configuration and adapter molecules in proper register. Because of its great length (450 nucleotides or more), only part of the messenger RNA molecule, including the reacting portion, can be attached to the ribosome surface at one time.

respect to location and size. To determine these properties in *E. coli* ribosomes, binding with the synthetic messenger poly U is being studied. Poly U is employed because it has a strong affinity for ribosomes, lacks secondary structure, is readily degraded by pancreatic RNase, and has a chain length that may be accurately determined.

It has been found that treatment of the complex of poly U and the 70 S ribosome or its 30 S subunit with pancreatic RNase results in degradation of most of the poly U except for an oligonucleotide firmly attached to the ribosome. Since free poly U would be degraded under the conditions used, the residual oligonucleotide must be protected by virtue of interaction with the ribosome. The homogeneity of the fragment is impressive and suggests that the binding site of the ribosome is at least large enough to accommodate a poly U molecule with $\approx$27 residues. Such a polynucleotide would have an estimated chain length of 184 Å, with 6.8 Å used as the translation per monomer unit. The chain is highly flexible, and many different configurations are possible, but certain arguments favor the concept that the active part of the template adopts the extended configuration during protein synthesis. The 30 S subunit is approximately disk-shaped with a thickness of $\approx$70 Å and a length of 160 to 180 Å. Thus the length of a fully extended poly U molecule of 27 residues is commensurate with the long dimension of the 30 S subunit to which it specifically binds. It may be imagined that a segment of template poly U of about this size is bound to the 30 S subunit and that the template as a whole moves along the subunit as it participates in protein or polypeptide synthesis.

Poly U combines with ribosomes to form polysomes rapidly and without prior incubation, unlike some synthetic and naturally occurring messengers such as the RNA of tobacco mosaic virus or T_2 messenger RNA, which require incubation before forming polysomes. In some cases this difference probably reflects the secondary structure of the messenger RNA, since prior treatment with CH_2O, which destroys H-bonded secondary structure, augments spontaneous polysome formation. Polyriboadenylic acid (poly A) binds poorly, even after CH_2O treatment. The poor binding of poly A to the ribosome may be caused by the relatively high energy state of its extended chain configuration. In support of this, the high hypochromicity shown by single-chain poly A is consistent with a stable folded structure in which adjacent adenine bases are in close contact.

BIOCHEMISTRY

Protein Structure

The digestive enzymes that originate in the pancreas have long been the objects of extensive kinetic and specificity studies. They are therefore ideal for the investigation of protein structure-function relationships. Two prevalent enzymes in this group have not hitherto been subjected to structural investigation: bovine chymotrypsin B and carboxypeptidase B, which arise by tryptic activation of the zymogens chymotrypsinogen B and procarboxypeptidase B in the intestine. Research with these proteins has been hampered by the notable ease with which the zymogens are activated and denatured during conventional isolation procedures that start with intact tissue. A preferable source of the zymogens is lyophilized pancreatic juice, from which gram quantities may be obtained by simple chromatographic methods developed here during the past few years.

The nature of the progress made in this research may be illustrated by the preliminary results obtained with chymotrypsinogen B. This protein is in many respects similar to the well-known zymogen chymotrypsinogen A: activation to the respective chymotrypsins appears to proceed by identical processes, and the specificities of the enzymes formed are very similar. However, there are obvious differences in amino acid composition. For structural study the single peptide chain of chymotrypsinogen B has been reduced with mercaptoethanol in denaturing solvents to break the five disulfide bonds. The thiol groups in the reduced protein have been masked by reaction with ethylene imine. The reaction is highly specific, and the S-β-aminoethylcysteine residues generated are potential sites for proteolysis with trypsin. When reduced aminoethylated chymotrypsinogen B is subjected to tryptic hydrolysis, a mixture of relatively small, soluble peptides is produced. The yields in which the peptides are formed are favorable. Since the residues found in these peptides account for all the amino acids in the parent protein, the tryptic fragments represent a logical access to the amino acid sequence of bovine chymotrypsinogen B.

Determination of Macromolecular Structures by X-Ray Diffraction

The detailed 3-dimensional spatial configurations of proteins and nucleic acids underlie their unparalleled capacities for highly specific catalysis, replication, information transfer, energy conversion, etc. Facilities have nearly been completed for determining such structures by single-crystal x-ray diffraction. An automatic x-ray diffractometer has been specified, constructed, and delivered; it is controlled by computer-generated tapes and operates continuously, unattended, to produce data tapes suitable for computer processing. When equipped with a detector system to measure three reflections simultaneously, designed and constructed here, the diffractometer will be one of the most reliable, rapid, yet economical single-crystal data collection systems extant. A computer program package for diffractometer control, error detection, and data processing has been written and tested. A high-intensity, rotating-anode x-ray generator has been specified and is under construction; it will make possible more rapid data collection and much better intensity statistics than are feasible with the usual x-ray sources. Meanwhile, a conventional single-crystal diffraction installation and a chemical laboratory have been put into operation. A new type of x-ray safety shutter has been designed and is in use; it reduces the possibilities of accidental personnel exposure drastically below those inherent in previous designs. In preparation for the isomorphous replacement technique used in determining large structures, some 30 compounds of uranium and thorium have been synthesized.

Exploratory studies are in progress of two enzymes already under biochemical investigation here, α-chymotrypsin and carboxypeptidase B; the combination of functional and structural studies should prove especially powerful in elucidating the stereochemical mechanisms involved. Carboxypeptidase B is a good choice for the additional reason that the structure of the similar A form is being determined elsewhere; a comparison of the two structures in light of their largely complementary specificities should be rewarding. Interest in α-chymotrypsin stems both from the extensive knowledge of its biochemical behavior and from the availability of structurally modified forms prepared here which are technically useful for diffraction studies.

Hemoglobin Synthesis

Study is being made of the effects on the synthesis of hemoglobin components of substances that are required for or adversely affect hemopoiesis. A number of vitamins and minerals are among the required substances; lead, certain drugs, and radiation depress hemopoiesis. In various kinds of animals a deficiency of iron, a required material, is known to depress erythrocyte formation and give rise to cells with a lower level of hemoglobin and higher level of nonheme or free protoporphyrin than normal. These altered levels are considered to be due simply to lack of iron in the cell. Tests in the iron-deficient duck indicated, as expected, that the erythrocytes contained a high level of free protoporphyrin. Also, the cells *in vitro* produced less heme and globin and more free porphyrin than normal cells. Addition of iron increased heme but not globin formation and prevented free porphyrin accumulation, but did not lower the preformed level of porphyrin. The findings suggest that the depressed globin formation and excessive porphyrin content of the the erythrocytes represent irreversible defects in the cell arising as a consequence of iron deficiency.

Pancreatic Enzymes

To gain detailed information about the protein composition of the bovine pancreatic secretion on a day-to-day basis, daily collections of juice obtained from a Holstein cow during an 8-week period were assayed for hydrolytic enzymes and zymogens (enzyme precursors). The enzymes and precursors studied accounted for $>85\%$ of the total protein in the juice. The zymogens of trypsin, chymotrypsin A, chymotrypsin B, carboxypeptidase A, and carboxypeptidase B were found to constitute practically constant fractions of the total protein. Occasional variations were attributable to spontaneous conversion of the zymogens to active enzymes and their subsequent autolysis. The proportions of deoxyribonuclease and amylase were somewhat variable. These findings indicate relatively constant quantitative relationships between proteins in the pancreatic secretion.

A low molecular weight material that inhibits trypsin was found in bovine pancreatic juice. The relationship of this material (which has been partially purified by gel filtration on G-75 Sephadex) to other trypsin inhibitors is not yet clear. With enzyme activity as a basis, the inhibitor is present

in the juice at a concentration equivalent to ≈1% of the trypsinogen concentration. Studies leading to the chemical identification of the inhibitor and to the determination of its distribution within the cell are currently under way.

Techniques have been developed for the isolation of zymogen granules from porcine pancreas. This will allow comparison of the proteins in granules and juice. The porcine system, because it is high in amylase, may be used to determine to what extent, if any, newly synthesized protein can bypass the storage stage at the level of the zymogen granules.

The quantitative relationship between the zymogens of trypsin and chymotrypsin A and B in fraction of pancreas obtained from tissue homogenates by differential centrifugation was examined and found to be constant. This is interpreted to indicate that there is no selective segregation of these zymogens within the pancreas.

Role of Serine in Enzyme Action

About 18 years ago it was discovered that the nerve gas diisopropyl fluorophosphate inhibits acetylcholinesterase, an enzyme involved in nervous function, and that the inhibition is attributable to phosphorylation of a serine residue in the enzyme. Analogous findings were then obtained with other enzymes. This appeared to identify a serine residue at the active site in all the enzymes. As time progressed, however, the presence of a serine residue at the active site and its role in enzyme reaction became ambiguous. First, the residue has no obvious catalytic properties. Second, kinetic anomalies appeared which could be explained in some cases by assuming the serine was a bypass of no direct consequence to the enzyme catalysis. Third, blocking of enzyme action by phosphorylation of serine could be explained by assuming that the added bulky group on the serine residue prevented access of substrate to the true catalytic residue, possibly histidine. Because of the importance of serine in a large number of enzymes of different activities and because it is one of the few residues whose identity with the active site seems most clear, a resolution of the dilemma was undertaken.

A single tosyl group was covalently bonded to the serine of the active site of chymotrypsin. Treatment of this tosyl chymotrypsin with base at 0° resulted in elimination of the tosyl group and production of a dehydroalanine residue in the place of the original serine. By use of radioactively labeled materials it was determined that the tosyl group was completely removed. In addition, assay indicated that one mole of dehydroalanine was produced for each mole of tosyl group eliminated. Since the dehydroalanine residue is smaller than the original serine, the steric access argument would be eliminated. If the hydroxyl group of serine plays an essential catalytic role, its elimination should result in an inert protein. If the hydroxyl group merely competes with normal substrates of the enzyme-catalyzed reaction, the protein should be equally as active as the native enzyme or more so. The dehydroalanine-containing protein was found to be inert. This demonstrates that serine plays an essential role in the catalytic action of chymotrypsin and other enzymes and is not simply a competitor of normal substrate. Models of the enzymes will therefore have to take into account the presence of serine at the active site and explain its unusual role in catalysis of a wide variety of reactions.

BIOPHYSICS

Bacteriochlorophyll-Protein Complex of Green Photosynthetic Bacteria

The water-soluble bacteriochlorophyll-protein complex characteristic of green photosynthetic bacteria has been obtained in a highly purified form from *Chloropseudomonas ethylicum*. Absorbancy indices at 415 mμ were determined on the bases of nitrogen content and bacteriochlorophyll *a* content. From these indices the chlorophyll-to-nitrogen ratio was calculated to be 8.2×10^{-4} mole/g. Preliminary amino acid analyses indicated that the protein moeity is 17.2% nitrogen. Thus the chlorophyll-to-protein ratio is 1.5×10^{-4} mole/g.

$$\mathrm{N} = \frac{M(1-\bar{V}d_0)}{d-d_0}\,[\mathrm{Chl}]$$

where M is the molecular weight of the complex, $\bar{V}$ the specific volume, d_0 the solvent density, d the solution density, and [Chl] the chlorophyll concentration. From sedimentation equilibrium studies in the ultracentrifuge, $M(1-\bar{V}d_0)$ was found to be 3.50×10^{4} g/mole. From measurements of d and d_0, the ratio of N to $M(1-\bar{V}d_0)$ was found to be 5.3×10^{-4} mole/g. Based on these data the value of N is estimated to be between 18 and 20.

From the chlorophyll-to-protein ratio and N, the molecular weight of the protein moiety in the complex is 1.2×10^5. The combined weight of chlorophyll and protein is 1.4×10^5. Tests for the presence of lipid and other components in the complex are currently under way.

An oversimplified spherical model of the photosynthetic particle ($MW\approx1.5\times10^6$) in green bacteria has a radius of roughly 80 Å. In the center of the particle is a sphere ($r=18$ Å) of bacteriochlorophyll; next is a protein shell extending to 35 Å. The outer layer contains *Chlorobium* chlorophyll, carotenoid, lipid, and protein. The bacteriochlorophyll-protein complex isolated from alkaline extracts corresponds to the 35-Å sphere.

In both *Cps. ethylicum* and *Chlorobium thiosulfatophilum*, the action spectra for light-induced cytochrome oxidation indicate energy transfer from *Chlorobium* chlorophyll to bacteriochlorophyll with a quantum efficiency of ≈70%. The quantum efficiency of the cytochrome reaction itself was found to be ≈50% *in vivo*. Further studies of chlorophyll-cytochrome interactions *in vitro* are planned.

Transport Through Biological Membranes

Studies are continuing of closed circuit systems composed of two barriers with different permeabilities, separating aqueous phases of different compositions. As already reported, when the aqueous phases contain ions, an electric current flows in the closed circuit. It is also easy to demonstrate the presence of other material currents even when the phases contain only neutral molecules. Experimentally it is quite difficult to quantitatively measure these material currents. For this reason such systems have perhaps not received the attention they deserve, despite the fact that they might well prove to be excellent models for the adsorption and secretion of neutral molecules by the kidney, the gut, or other sites in living animals in which material transfer through two or more membranes is effected. In the theoretical analysis of such systems it is useful to introduce the concept of a chemomotive force which is entirely analogous to that of an electromotive force, employed when the materials being transferred are ions.

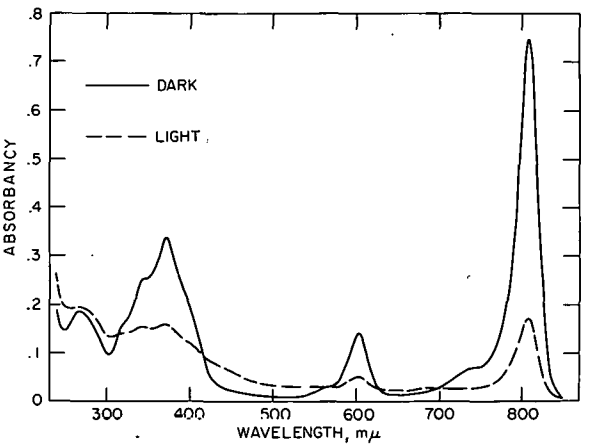


Figure 6. Absorption spectra of bacteriochlorophyll-protein solutions. The solid curve is for a sample kept in the dark. The dashed curve is for a sample exposed to a 150-W reflector spot lamp for 7 hr. Isobestic points are at 308 and 415.0 mμ.

Membrane transfer systems in which the energy required to maintain a stationary state is derived from an enzymatically catalyzed chemical reaction are also under study. In such systems it is found that ions can move through an inert cellophane membrane contrary to both their concentration and electrochemical potential gradients during the approach to a stationary state. In a system in which the hydrolysis of urea by urease is taking place, potassium, sodium, and lithium ions accumulate in the enzyme phase, while chlorine ion appears in higher concentration in the nonenzyme phase. The system has little ionic selective power at the chemical reaction rates and membrane fluxes of the metabolites so far achieved, being only ≈2% for the potassium-sodium pair and 4% for the potassium-lithium pair in favor of potassium's being higher in concentration than the other ion in the enzyme phase when the respective ions are of equal concentrations in the nonenzyme phase. Attempts are being made to achieve higher fluxes, since the theory indicates that the log of the selectivity should be proportional to the fluxes of the chemical reactants.

ENVIRONMENTAL BIOLOGY

Metabolism of Plants in the Field

Measurement of the metabolism of plants in the field is important because it enables immediate appraisal of function under natural conditions and extends greatly the possibility for experimental manipulation of plants. The central problems involved in field measurements of metabolism have

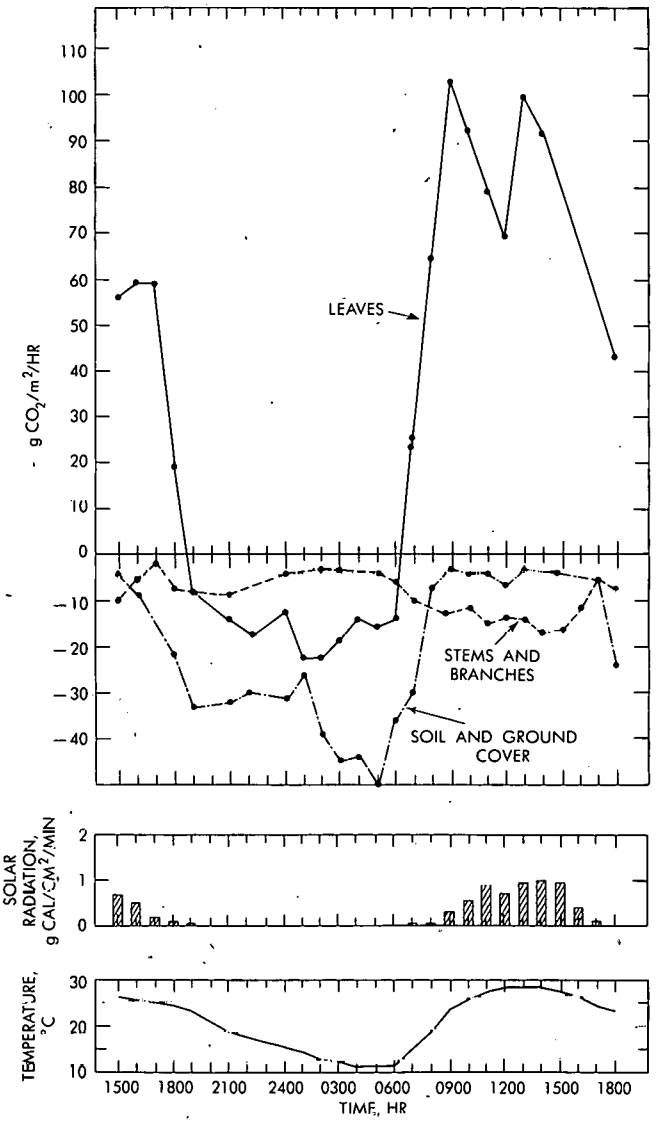


Figure 7. CO_2 exchange in white oak in the field. A system for monitoring CO_2 exchange of tree leaves, stems and branches, and of ground cover, and other pertinent variables, has been established in a natural forest for study of radiation effects. The data are for white oak on a bright day in August 1963. Uptake of CO_2 by leaves during the daylight hours and loss during absence of solar radiation are evident.

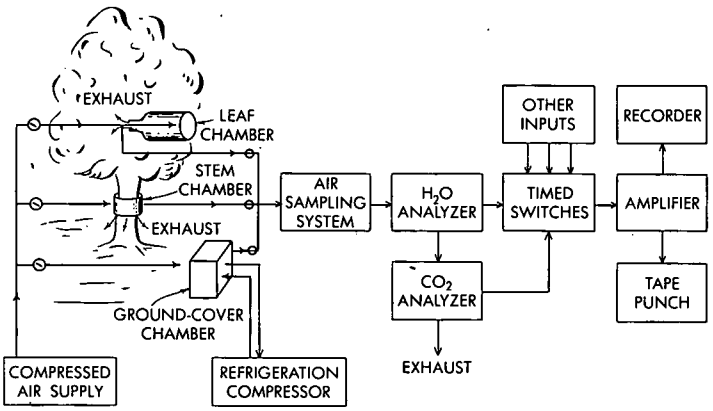


Figure 8. Automatic sampling and data-recording system for monitoring metabolism of plants in the field. Air is supplied at a constant rate to each of the three types of assimilation chambers shown. The exhaust from these chambers is sampled, its CO_2 content is measured and compared with the CO_2 content of the air supplied, and these measurements, with pertinent environmental measurements, are recorded on a punched tape. All data are then handled by machine.

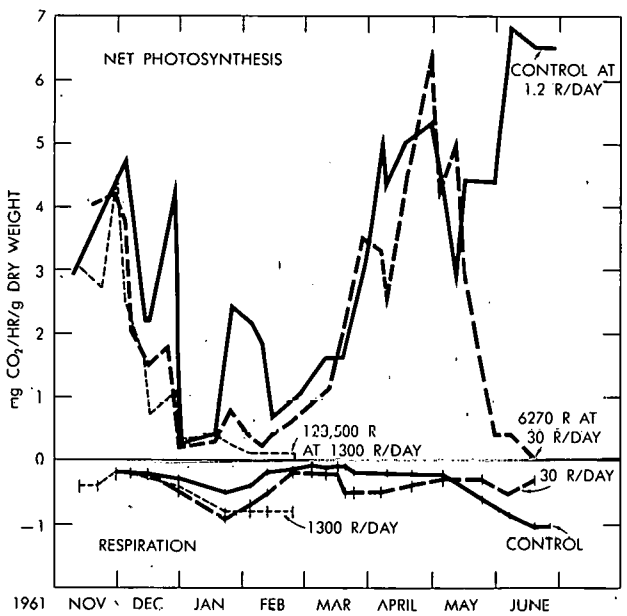


Figure 9. Effect on *Pinus rigida* (1961 needles) of prolonged exposure to gamma rays in the field. Weekly maximum rates of CO_2 gain through photosynthesis and loss through respiration were estimated from data supplied by an automatic sampling and data-recording system.

been two: First, enclosures needed for the measurements must not alter natural environmental conditions. Second, there is need to monitor a host of environmental variables, many of which can be controlled under greenhouse or laboratory conditions. Monitoring of environment is a complex and technical procedure which produces large volumes of data which are in themselves difficult to handle. During the past three years ecologists at Brookhaven, with the assistance of the Instrumentation Division, have built and operated a system for measuring the metabolism of plants in the field and recording the data with pertinent environmental measurements on punched tape. The data on the tape can be handled automatically by the computer, which greatly simplifies analyses.

The system was designed around the three types of assimilation chambers: leaf, stem, and ground-cover chambers. All chambers operate on the same principle: air is supplied from a central source where its flow rate is measured. The air passes over the plant and is exhausted to the atmosphere. The CO_2 content of this exhaust is measured by infrared absorption. Air and leaf temperatures within leaf chambers hover within 2°C of that of ambient air. Stem chambers operate similarly, except that they are opaque. Ground-cover chambers are relatively large and must be cooled by a refrigeration unit small enough to be taken to the field. Data from these chambers along with other data on microclimate are fed through the timed switches to the tape punch and are handled by the computer thence forward. The measurements, used with detailed data on the structure of the forest, allow calculation of rates of metabolism of populations and of the entire forest. The CO_2 exchange of pines under two levels of radiation was measured during the winter and spring of 1961-62, when the radiation source was first installed. Trees exposed to low rates of irradiation showed the normal depression of photosynthesis during winter and recovery in the spring; irradiated trees died during the winter, but maintained low rates of CO_2 absorption until immediately prior to the death and dehiscence of the needles. During the past winter photosynthesis was measured at low rates even on days when leaf and air temperatures within the chambers were within 1°C of freezing. This type of field measurement seems to hold much promise in elucidating the function of ecosystems and in clarifying relationships between laboratory observations and behavior in the field.

Medical Research

In developing its research program, the Medical Department has several responsibilities. It has the broad responsibility to advance medical knowledge and the more specific responsibility to advance understanding of the effects of ionizing radiations in man. Some of the investigations are directed toward beneficial applications of these radiations and toward improvement of measures to prevent or counteract their detrimental effects. Other investigations are centered on elucidation of disease states and development of improved methods of diagnosis and therapy. Investigations in these two areas complement each other, since the study of radiation effects contributes to the understanding of diseases, and vice versa, yet the pace of progress in both is controlled by the advances in knowledge of the normal biological processes of man.

A great influence on these advances is the rapid development of new techniques for the examination of structures and mechanisms at the molecular as well as the subcellular and biochemical levels of organization. Information revealed through these techniques and with the aid of such instruments as the electron microscope, dictates re-examination of medical and biological phenomena at even finer levels of organization. Findings from such investigations present the Department with the additional responsibility to exploit them for clinical applications.

The diversified talents and extensive facilities uniquely concentrated at Brookhaven provide the Department with unusual advantages for pursuing its objectives. Its broadly based program incorporates the experience and skill not only of those devoted to research in the field of medicine but of many from the various disciplines in other Departments and from collaborating institutions. The interchange of ideas, information, facilities, and services is essential for the staff to keep abreast of the new developments that have medical implications, and within the framework of the program opportunities are limited only by the scope of the vision and interest of the individual investigator.

Thus, in its role of service to Associated Universities, Inc., to the Atomic Energy Commission, and to the medical community, the Department's primary responsibility is the assemblage of talented scientists capable of elucidating biological phenomena at the finest level of organization and experienced physicians capable of relating these researches to clinical studies.

Specific examples of research under way are given in the following pages. The report is not comprehensive, and the reader may obtain additional information from publications of the Department.

BIOLOGICAL EFFECTIVENESS OF FAST NEUTRONS

The series of experiments to determine, in various tissues of the mouse, the relative biological effectiveness (RBE) of fast neutrons of relatively discrete energies as compared to x or gamma radiation were continued. The fast neutron irradiation technique employs a 3-MeV Van de Graaff accelerator with a tritium target and permits accurate determination of effects in tissue of fast neutrons as a function of their energy level as well as comparison with the "standard" x or gamma rays.

Groups of mice were exposed to graded doses of (1) neutrons of 14 MeV at 1 of 3 dose rates covering a 2-decade span, or (2) neutrons of 1.80 MeV. Comparison exposures of other groups employed Co^{60} gamma rays. Determinations of spermatogonia depletion were made microscopically from testis sections and revealed an average RBE of 2.7 for the 14-MeV neutrons and 5.4 for 1.80-MeV neutrons. The 14-MeV neutron results suggested a slight dependence upon dose rate. This effect is appreciable with x or gamma rays, but could not be demonstrated previously with 0.6-MeV neutrons. The RBE values found appear to be related to the linear energy transfer (LET) associated with each type of radiation, being least for x and gamma rays, and highest for 1.80-MeV neutrons.

In further studies of lens opacities caused by radiations such as fast neutrons, a slit-lamp microscope was employed in conjunction with a mechanical mouse restrainer as shown in Figure 1. Anterior and posterior lens opacities, found to differ significantly in appearance and growth, were scored separately, rather than "lumped" as has been the usual practice elsewhere.

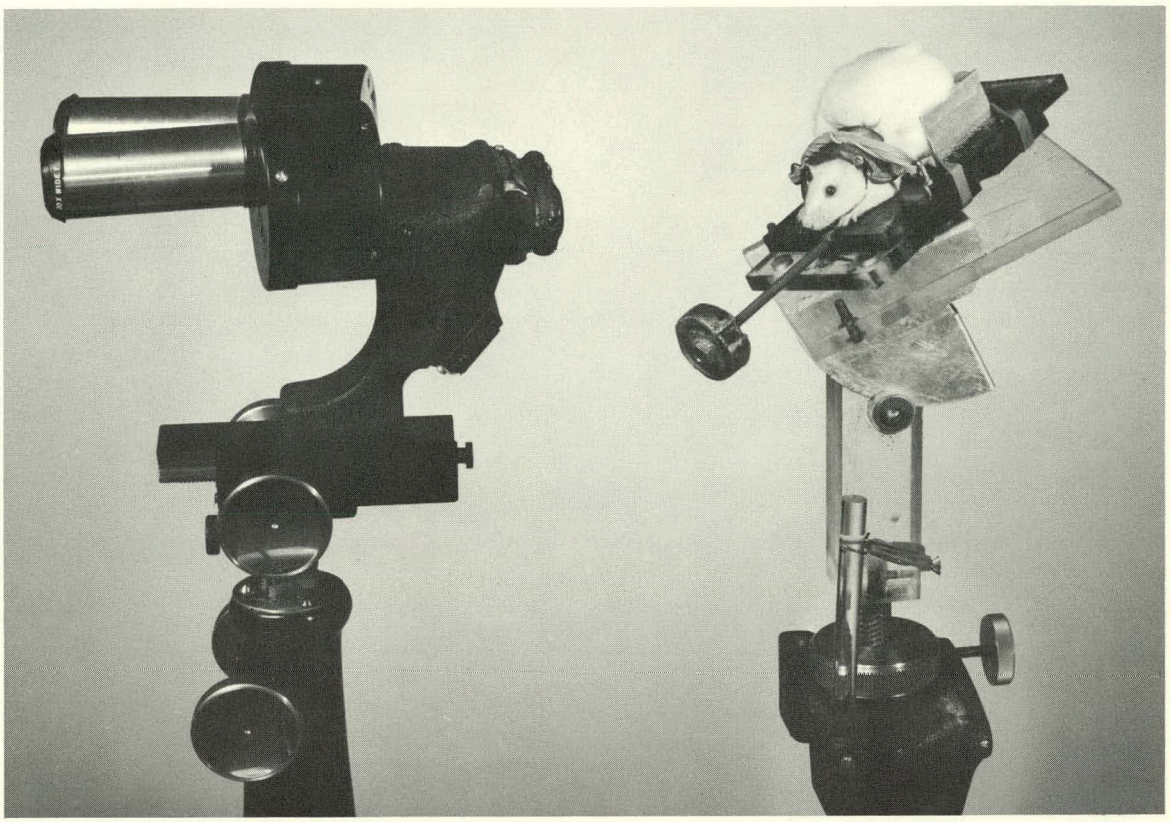


Figure 1. Lateral view of the facility employed in examination of the mouse, showing the approximate position for study of the right eye. The light source, usually positioned almost parallel and adjacent to the microscope, has been omitted for clarity.

Lens opacification was studied as a function of time following the exposure of 16-wk-old mice to low and divided doses of 250-kVp x rays or to neutrons at energies of either 0.43 or 1.80 MeV. (The monoenergetic fast neutron technique, utilizing a 3-MeV Van de Graaff generator in conjunction with a tritium target, was employed for these studies in the same manner described in previous Bulletins for earlier studies of other cell systems in the mouse.) The data have revealed to date an increase in lens opacification for all 3 radiations with either time or dose, even for values of the latter as low as 1 rad of neutrons. An RBE of ≈ 10 has been obtained for lens opacification by neutrons of either energy tested, when compared to x rays. Posterior opacities have been found to appear earlier and progress more rapidly than those located at the anterior pole of the lens.

Studies on fine structure alterations during formation of radiation-induced cataracts, using conventional and electron microscopy, are under way.

BIOLOGICAL AND PHYSICAL FACTORS OF NEUTRON REACTIONS

During the past year, the physical studies were directed primarily toward the development of a dosimetric system capable of evaluating the various components present in a mixed field of reactor radiations. By using the results from the physical dosimetry, the optimal physical conditions can be chosen for the application of the neutron capture process to the therapy of neoplasms. The neutron capture therapy technique involves the localization in a tumor of a capture element, such as B^{10}, Li^{6}, or U^{235}, which interacts strongly with thermal neutrons reaching the tumor site. A neutron beam, of necessity, exposes some intervening and adjacent normal tissue; the absorbed dose to these normal tissues must be kept at a minimum. The poor penetration in tissue of a thermal neutron beam has previously militated against successful use of the technique. An epithermal beam has

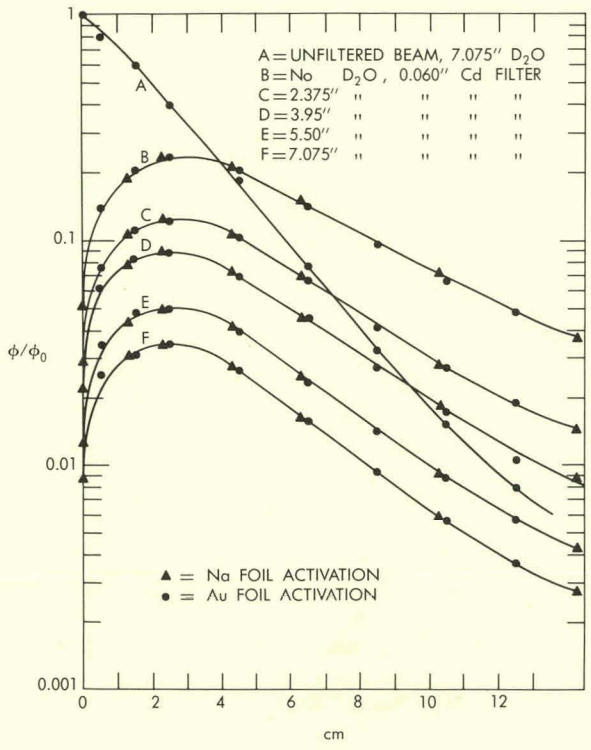


Figure 2. Neutron flux in tissue-equivalent phantom head vs distance for various D_2O thicknesses.

been developed which gives increased neutron penetration in tissue, such that the neutron flux density in the clinically interesting region from 0 to 7 cm is always greater than that at the surface (Figure 2). This increased penetration is in contrast to that of the thermal beam, which falls off by a factor of $\approx$16 in 7 cm.

Threshold detectors and tissue-equivalent chambers have been used to evaluate the dose to a small amount of tissue from fast neutrons at both the thermal and epithermal beam ports of the Medical Research Reactor. Results from the two different methods agree to within 15%. Activation foils and graphite-CO_2 chambers have been used to evaluate the neutron flux density and gamma exposure, respectively. Results of the above measurements have shown that (1) the most favorable conditions for the irradiation of tissue with epithermal neutrons occur with all the D_2O moderator in place, and (2) even with the installation of a cadmium filter in the reactor reflector to produce an epithermal beam, the gamma contamination from the reactor is insignificant.

A system of tissue-equivalent chambers with replaceable electrodes has been developed to evaluate the absorbed dose from fast neutrons, thermal neutrons, and gamma rays in any kind of tissue-equivalent phantom. This information is necessary to evaluate the biological results of experiments and to estimate the amount of radiation that can be delivered before the tolerance of normal tissue is exceeded. Typical results are shown in Figures 3 and 4, as measured along the axis of a phantom man at the epithermal beam port. Results of the above measurements and of measurements made at the thermal beam port have shown:

1. The amount of gamma contamination originating from the reactor at both the epithermal and thermal beam ports is relatively low.

2. The epithermal beam has the capacity to give a dose to the tumor that is up to 1.6 times the dose to boron-free tissue, at all depths >1 cm in a phantom head (assuming the selective presence in tumor of a neutron-capturing isotope at a concentration that would give the same effect as 35 μg/g B^{10}).

3. The addition to normal tissue of 1/6 the tumor B^{10} concentration does not greatly affect the tumor tissue/normal tissue dose ratio, because the epithermal beam delivers a minimal thermal neutron flux density in the sensitive region of the surface tissue.

Accompanying biological experiments are summarized below.

Incomplete studies using HeLa cells indicate that the radiobiological response, in terms of survival curve shape and dependence on dose rate

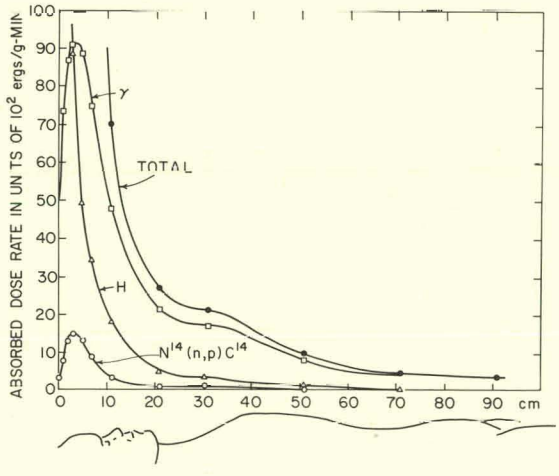


Figure 3. Absorbed dose rate as measured on the long axis of a phantom man at the epithermal beam port of the Medical Research Reactor. Long axis of man coincides with beam axis. Reactor power, 5 MW.

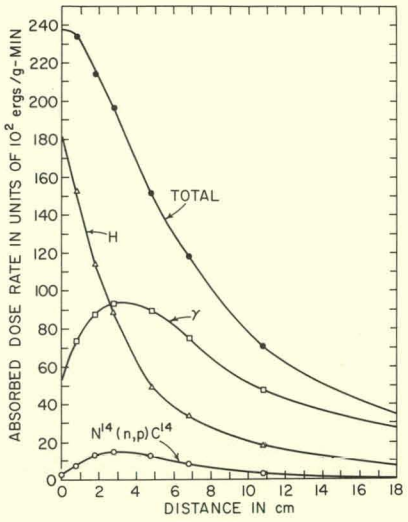


Figure 4. The region from 0 to 18 cm in Figure 3, redrawn to show more detail.

and oxygen tension, is consistent with that expected from high-LET radiation.

Studies with a variety of naturally occurring tumors in dogs indicate that inorganic boron is variably partitioned between tumor and normal tissue. The blood boron concentration usually exceeds that of tumor or normal tissue stroma; thus normal vessel endothelium may receive a higher dose than does tumor tissue.

The "whole-body" dose distribution for various geometries of exposure has been determined. The dose obviously depends on the length of exposure, but is appreciable with exposures considered to be therapeutic.

Experiments with swine are under way in an effort to estimate dose-equivalent (loosely, rem-dose) curves for these beams.

EFFECTS OF HIGH ENERGY PARTICLES ON MAMMALS

With the cooperation of the staff of the Cosmotron, studies of the effects of protons in the 2.0 to 3.0-BeV range are continuing, and studies with π^- mesons have been initiated.

Primary effort during the past year has been devoted to the development of methods of delivering completely uniform whole-body proton radiation to small animals. The construction of special apparatus was completed, and the LD_{50} for mice for 2.2-BeV protons, uniformly distributed over the cross-sectional area of the animal's body, has been determined. Departures from this "flat" field of as little as 15% have the effect of lowering the lethal dose by nearly one-half. This effect is thought to be due to a preferential irradiation of radiosensitive organs and tissues, since the irradiations are given along the longitudinal body axis. Pending adequate dosimetric measurements, values for the RBE of protons in this energy range will be calculated. Methods are being designed for study of LET and of the nature and contribution to dose of the secondary particles resulting from nuclear interactions of the proton beam.

Because of theoretical considerations which attribute a high depth-to-surface dose ratio to π^- mesons, an investigation with regard to possible use of such particles in radiobiology and radiation therapy is in progress. When a beam of π^- mesons is stopped in an absorber, many of the particles will be captured at the end of their paths by one of the absorber nuclei, and free energy equivalent to the meson's rest mass ($\approx$140 MeV) will be set free. A low-intensity beam from the Cosmotron was used, and positive and negative particles of low momentum were studied with a tissue-equivalent ionization chamber and a counter telescope. The momenta of the particles were chosen to correspond to a range of 6 in. in wet tissue. The identification of the π^- mesons among other particles of the same charge and momentum was done by means of coincidence-anticoincidence techniques, which make it possible to measure the effects of interest even in the presence of a heavy background of undesired particles. Absorption curves indicating the number of particles with increasing penetration into an approximately tissue-equivalent absorber as well as range curves of the beam were determined. A multichannel analyzer supplied information on the amplitude distribution of the electronic pulses that result from the particles' energy losses in plastic scintillation counters. The change in this distribution with increasing absorber depth indicates the increase of energy transfer from the particles to the absorber material and makes it possible to observe the meson capture events with their particularly high energy release.

EXTRACORPOREAL IRRADIATION OF THE CIRCULATING BLOOD: EFFECTS ON LYMPHOCYTES AND RED CELLS

A significant improvement in the technique of extracorporeal irradiation of the circulating blood

was the development of improved arterial venous fistulae. These provided flow rates up to 1500 ml/min with a transit dose variable of from 25 to 900 rads. In general, the system now provides for an exchange of 1 blood volume through the irradiation field every 7.5 min. With transit doses of the order of 50 rads, a significant lymphocytopenia was attained. Recovery of the peripheral lymphocyte takes place over a very prolonged period of time (40 or more days).

In studies on extracorporeal irradiation combined with thoracic duct drainage, a very rapid exchange of blood lymphocytes with lymphocytic tissue lymphocytes has been shown to occur. The outflow of lymphocytes from the lymph duct primarily reflects feeding of the lymphocytic tissues by blood lymphocytes, rather than the reverse.

Studies have been initiated to compare the results of extracorporeal irradiation of leukemic and normal cows. It has been demonstrated that a lymphocytopenia can be induced in bovine chronic lymphocytic leukemia; however, the therapeutic effectiveness of this has not yet been evaluated.

With improved techniques of autotransplantation and homotransplantation of skin of cows, studies of the influence of lymphocyte depletion upon homotransplantation have been initiated. Similarly, studies are under way on the influence of lymphocytopenia produced by extracorporeal irradiation upon the induction of a primary immune response by tetanus toxoid.

RADIOSENSITIVITY OF ANTIBODY RESPONSES

Mice were immunized with either a single injection of tetanus toxoid only or a single injection of toxoid complexed with mouse antitoxin (anti-

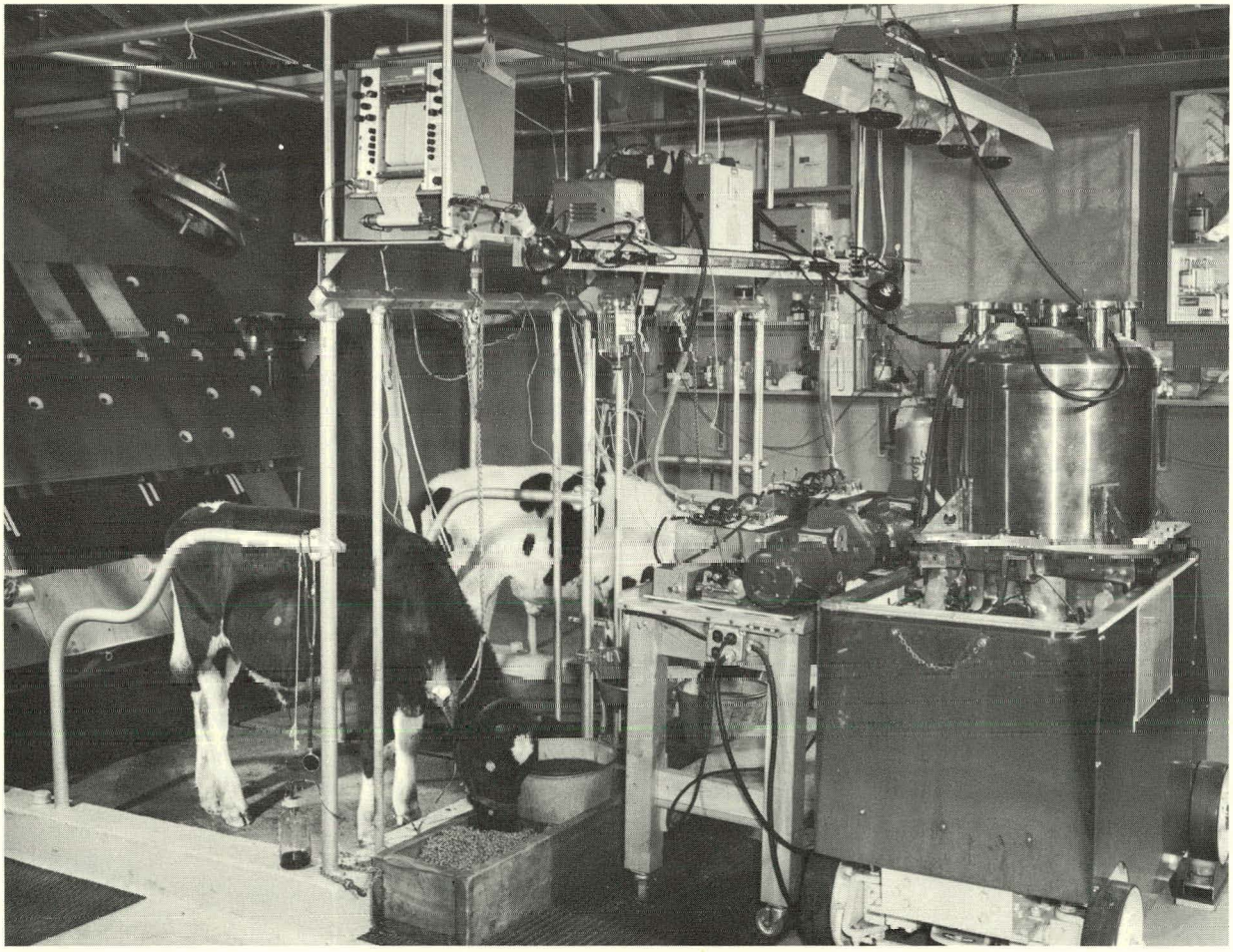


Figure 5. Extracorporeal irradiation of the blood in the new large animal facility.

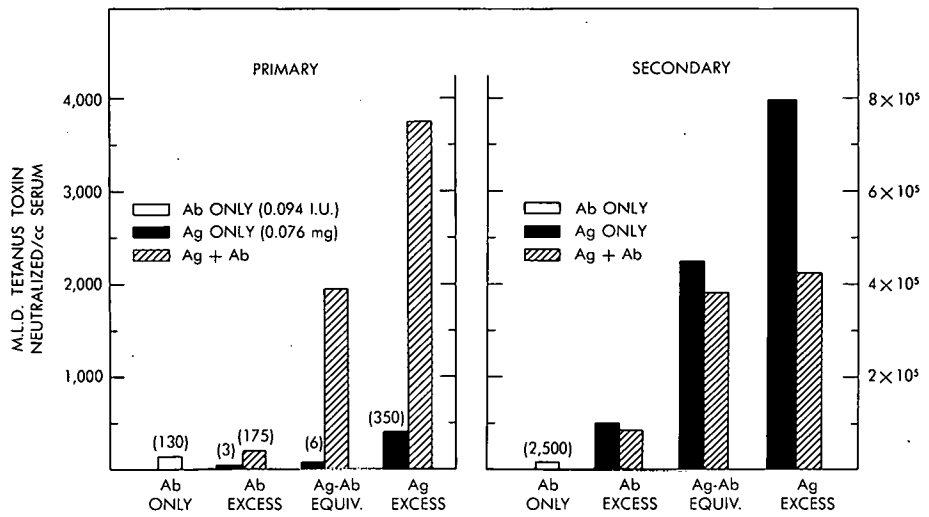


Figure 6. Comparison of primary and secondary tetanus antitoxin responses in nonirradiated mice elicited either by toxoid (antigen) or by the same amounts of toxoid complexed with mouse antitoxin. (Ag = antigen; Ab = antibody.)

body to toxoid). The complexes were prepared in toxoid-antibody ratios of antibody excess, equivalence, and toxoid excess. Primary antibody responses were detected earlier along with greatly increased amounts of antibody in mice immunized with the complexed toxoid as compared with responses obtained in mice immunized with the same amounts of antigen only. Enhanced antibody responses were also obtained in irradiated mice (400 rads) when the various complexes were injected 1 day after irradiation. The greatest degree of enhancement of primary antibody responses in normal (Figure 6) and irradiated mice occurred when the complexes were prepared in ratios of equivalence and antigen excess. The demonstration of the enhancement phenomenon provides conclusive evidence that the antibody portion of the complex need not be of foreign origin in order to elicit enhanced antibody formation. Secondary antibody responses were slightly depressed when booster injections of the various complexes were used to elicit booster responses. Corresponding depression of secondary responses was observed in irradiated mice (400 rads) given booster injections of the various complexes. Complexes of toxoid and mouse antibody are more efficient in eliciting primary responses, whereas the same amount of antigen only is more efficient in eliciting booster responses.

Studies on the role of the thymus in the development of immunologic competence dealt with the effect of thymectomy in newborn mice upon the development of their ability to produce antibody as adult animals. The thymus was surgically removed from 1 to 8 days after birth. The thymectomized and the nonthymectomized littermate control animals were given a primary immunization with tetanus toxoid when 4 wk of age. A booster injection of toxoid was given 3 wk later to elicit secondary antitoxin response. With these time intervals, thymectomized mice showed only slightly impaired primary antibody response but severely repressed secondary response as compared to the littermate controls. These data indicate that postnatal thymectomy does not abolish the ability to respond later to antigenic stimulation at the age of 4 wk.

IN VIVO MEASUREMENT OF RADIONUCLIDES IN MAN: KINETIC STUDIES AND BODY BURDEN MEASUREMENT

The sensitivity and precision of the whole-body counter permits the measurement of the biological turnover of various elements in man with low levels of tracer. The whole-body counter also permits the rapid identification and quantification of body burdens of gamma emitters in large populations. A FORTRAN II program for the IBM 7094 was developed for reduction of complex pulse-height data to quantify the levels of Cs^{137}, Zn^{65}, and K^{40} in 600 Brookhaven employees. The program (re-

ferred to as GAMSTRIP) performs a nonlinear least-squares fit of a Gaussian function to the total absorption peak. The associated Compton contribution required in the program is computed by interpolation from an experimentally derived matrix of seven monoenergetic gamma rays in a phantom.

Compartmental models of calcium and strontium metabolism were developed by analogue and digital (IBM 7094) computer analysis of the Sr^{85} and Ca^{47} data from short-term kinetic tracer studies. Kinetic studies carried out on patients with normal skeletal metabolism and patients with partial parathyroid deficiency were extended to permit comparisons of the biological turnover following chronic administration of Sr^{85} and Ca^{47} with that following acute parenteral administration. A current chronic feeding study, using Sr^{85} in four patients, allows a more complete labeling of the "stable" bone compartments with long time constants. By this means it should be possible to derive the function describing the rate of bone resorption and long-term exchange from "stable" bone compartments.

A new technique was developed to measure Sr^{85} and Ca^{47} turnover in a bone compartment by external scanning with a collimated detector. Data from a study on several patients with this technique show differing uptakes in contralateral homologous bones as a function of the amount of use of a limb.

The kinetic studies of calcium and strontium turnover in rats have been continued and supplemented by the use of a newly developed neutron activation technique for the analysis of stable strontium in plasma and tissues. This analytical technique has been applied in a study of the effects of stable calcium and strontium feeding on the turnover of Sr^{85} in blood and other tissues.

Studies on the *in vivo* measurement of Thorotrast have continued with emphasis on the gamma-ray spectrometric analysis. Because of the complexity of the decay chain of Th^{232}, the interpretation of the spectral data is carried out with the IBM 7094 computer. The levels of gamma-emitting daughters of Th^{232} (Tl^{208} and Ac^{228}) in various organs were determined by comparison of the Thorotrast patient's spectrum with that of a phantom containing a calibrated solution of $Th(NO_3)_4$ at secular equilibrium.

STUDIES ON HYDROXYLYSINE AND COLLAGEN

Collagen forms ≈30% of the protein of the mammalian body and serves to hold together the

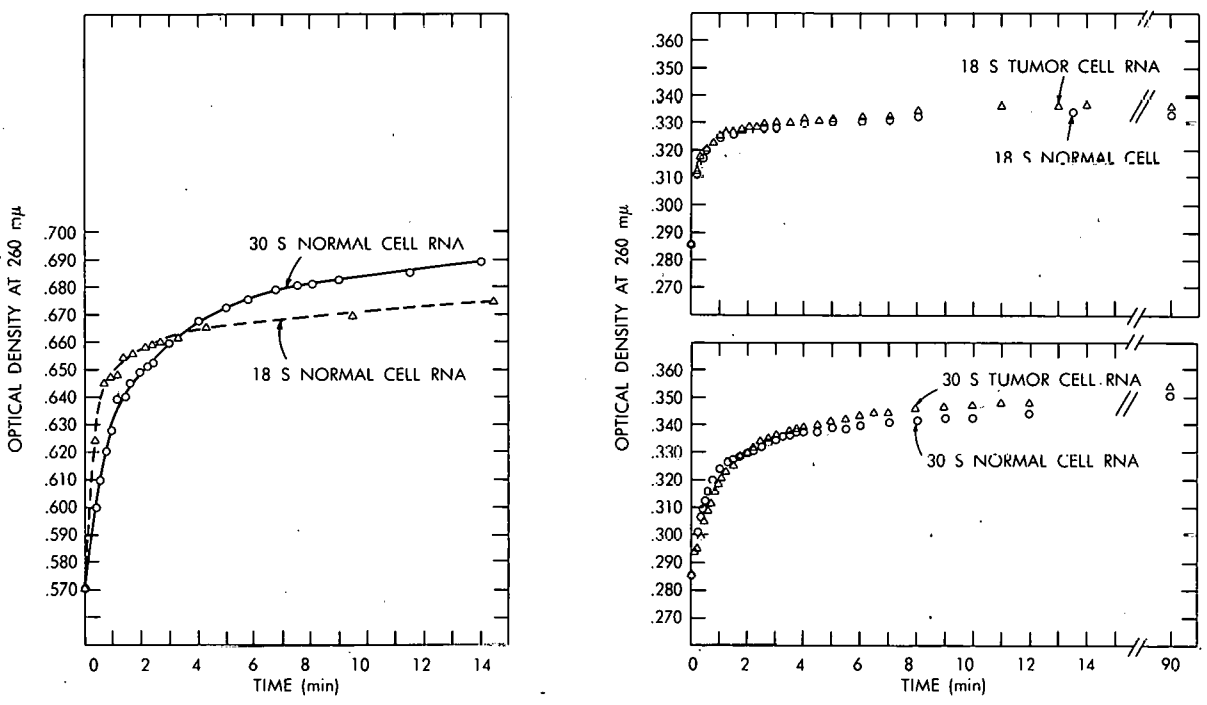
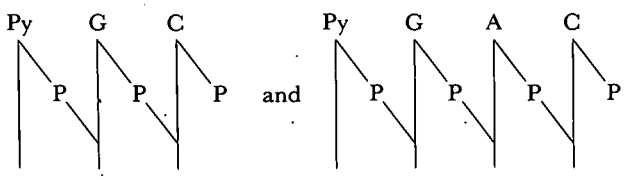


Figure 7. Pancreatic ribonuclease digestion of normal and tumor tissue RNA.

structural form of the organs. Hydroxylysine is an amino acid that occurs only in collagen and presumably gives the latter some of its unique properties. Hydroxylysine has the structure $NH_2 \cdot CH_2 \cdot CH(OH) \cdot CH_2 \cdot CH_2 \cdot CH(NH_2) \cdot COOH$. If it is bound in the collagen molecule by the usual peptide linkage of its carboxyl and adjacent α-amino group, the hydroxyamino group $NH_2 \cdot CH_2 \cdot CH(OH) \cdot$ shown at the left of the above chain should be free and capable of entering into chemical reactions unless it either (1) is made inaccessible by steric hindrance due to its geometrical place in the protein molecule, or (2) is made nonreactive by chemical combination of the NH_2 or OH group. Reaction with periodate oxidizes the group $NH_2 \cdot CH_2 \cdot CH(OH) \cdot R$ to $NH_3 + CH_2O + OCH \cdot R$. With free hydroxylysine the reaction is complete in a few minutes. When the periodate reaction is applied to gelatin made from the collagen of bone, however, only 60% of the hydroxylysine is found to be destroyed, 40% being completely nonreactive. To determine whether the nonreactivity is due to steric hindrance, the gelatin has been split into small peptides by digestion with collagenase, and the periodate reaction has been applied to the digest. If the nonreactivity were due to steric hindrance, the enzymatic hydrolysis to peptides should remove the hindrance. However, the digest showed, as did the intact gelatin, 40% of the hydroxylysine to be nonreactive. The results indicate that either the NH_2 or the OH group of the hydroxylysine in collagen is probably bound in chemical linkage. Such combination could contribute cross-links essential to the structure of the collagen molecule. Work is planned to identify the chemical nature of the linkage.

NUCLEIC ACID STUDIES IN NORMAL AND TUMOR-VIRUS-INFECTED CELLS

Studies have been initiated of the structure of ribonucleic acids (RNA's) extracted from normal chick-embryo chorioallantoic membranes and those infected with the Rous sarcoma virus. An analysis of the structure of 30 S and 18 S RNA's from normal chorioallantoic membrane cells has shown that there are distinct differences in the nucleotide sequences of these two RNA's (Figure 7). Following diethylaminoethyl-Sephadex ion exchange chromatography and analysis of the oligonucleotide products of ribonuclease digestion, it was found that 30 S RNA appears to have a much greater abundance than 18 S RNA of the following proposed sequences of nucleotides:



where

Py = pyrimidine nucleoside,
P = phosphate linkages,
G = guanosine,
C = cytidine,
A = adenosine.

After infection of embryos with the Rous sarcoma virus, identical differences in 30 S and 18 S

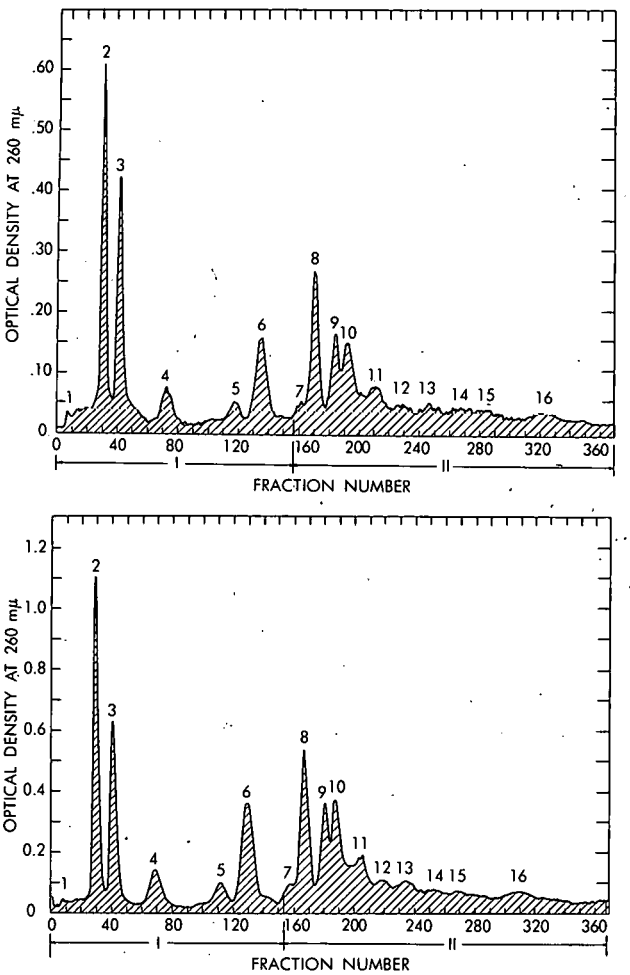


Figure 8. Chromatographic profiles of ribonuclease digestion products of normal microsomal RNA (top) and Rous sarcoma microsomal RNA (bottom).

tumor RNA's were found; however, no differences between normal and tumor RNA were detected in either the 30 S or 18 S RNA's. The patterns of ribonuclease digestion were similar, and chromatograms of the digests revealed no significant differences between normal and tumor extracts.

A comparison of oligonucleotide digestion products of extracts from highly purified nuclei and from the cytoplasm of normal membrane cells has indicated a similarity in nucleotide sequence arrangement (Figure 8). This finding supports recent evidence from other laboratories that some RNA's of normal cell nuclei are similar to cytoplasmic ribosomal RNA's. Additional studies with ribosomal RNA's extracted from the cytoplasm and RNA's from purified cell nuclei of Rous sarcoma cells indicated very close similarity of clusters of nucleotides between normal and tumor tissue, which confirmed the findings with 30 S and 18 S total cell RNA. These results with Rous sarcoma tissue suggest that in this particular tumor ribosomal RNA's may be largely unaltered in structure and that these RNA's may be functioning in a fashion similar to normal cells in the synthesis of cell proteins.

In another study, iododeoxyuridine (IDU) labeled with a gamma-emitting isotope of iodine is used to label cells with little or no turnover rate in the adult. The labeled IDU is administered to mice at a time when these cells are rapidly proliferating, i.e., just before or soon after the mice are born. At present this is being accomplished by injecting the label into pregnant mice 1 to 5 days before parturition. Nearly all the tissues in the entire litter are found to be labeled. However, as time passes the cells with a short life-span die and their label is excreted. By the time the mice are 2 months old, >80% of the label is present in cells with a life-span >1 yr. The determination of the distribution and longevity of these cells in various tissues and the effect of ionizing radiation and mutagenic chemicals on the viability of these cells is in progress.

VITAMIN AND AMINO ACID METABOLISM IN NEOPLASIA

In studies of DL-tryptophan metabolism on anemic patients, a controlled diet was given 7 days prior to an oral dose of 2 g L-tryptophan. Urine analysis for kynurenic acid, xanthurenic acid, indican, anthranilic glucuronide, *o*-aminohippuric acid, acetylkynurenine, kynurenine, and hydroxykynurenine showed no abnormal excretion of these urinary products in the patients studied.

As a therapeutic measure for one patient (21 years old) with microcytic hypochromic anemia whose urinalysis showed very high urinary quinolinic acid, N^1-methylnicotinamide, and N^1-methyl-2-pyridone-5-carboxamide hydrochloride levels, vitamin B_6 was administered (100 mg, three times a day) for a period of 2 wk and the 2 g L-tryptophan overload test repeated. The high levels of urinary quinolinic acid, N^1-methylnicotinamide, and N^1-methyl-2-pyridone-5-carboxamide hydrochloride were lowered significantly after vitamin B_6, and the increase (after tryptophan overload) in the levels of these urinary components was much less than that observed prior to the vitamin B_6 treatment. The urinary excretion data suggested a relationship between quinolinic acid production and vitamin B_6. The straight-chain compound (1-amino-4-formyl-buta-1,3-diene-dicarboxylic acid) formed when the ring of 3-hydroxyanthranilic acid is split apparently requires vitamin B_6 for its metabolism down to CO_2, and when the tissue B_6 level is low or its utilization is blocked, the 1-amino-4-formyl-buta-1,3-diene-dicarboxylic acid cyclizes to form quinolic acid, which appears as an increased level of quinolinic acid (and its products) in the urine.

In the study of 3-hydroxyanthranilic acid–carboxyl-C^{14} metabolism, a female achondroplastic patient with normal tryptophan metabolism, as determined by quantitative urinary analysis for a number of tryptophan metabolites before loading with 2 g L-tryptophan, was given orally 14.088 mg carboxyl-labeled 3-hydroxyanthranilic acid containing 51.055 μCi C^{14}. The expiration of $C^{14}O_2$ by the patient was similar to that observed in rats, except that a smaller percentage of the dose was expired as $C^{14}O_2$.

The percentage of urinary C^{14}-quinolinic acid was found to be much higher in man than in the rat, which suggests some quantitative difference in the manner in which hydroxyanthranilic acid is metabolized in the two species. The order of magnitude of percent of activity present in each isolated urinary component suggested that renal clearance of compounds as well as dosage administered plays a role in the over-all results obtained with labeled compounds. The normal pathway of hydroxyanthranilic acid metabolism was assumed to be via quinolinic acid, nicotinic acid, N^1-methylnicotinamide, and then pyridone; therefore, it was noteworthy that the order of components ex-

creted was quinolinic acid, pyridone, N^1-methylnicotinamide, and nicotinic acid.

The total radioactive content of the serum seemed to consist of at least two components, a major portion that does not precipitate with the serum proteins, and a minor portion that does. This bound activity decreased with time at a much slower rate than did the soluble activity. The chemical nature of the protein-bound radioactivity was not determined; however, it may result from incorporation of breakdown products of hydroxyanthranilic acid or intact hydroxyanthranilic acid. It is possible that this kind of tissue-binding of hydroxyanthranilic acid or its metabolites may play a role in carcinogenesis.

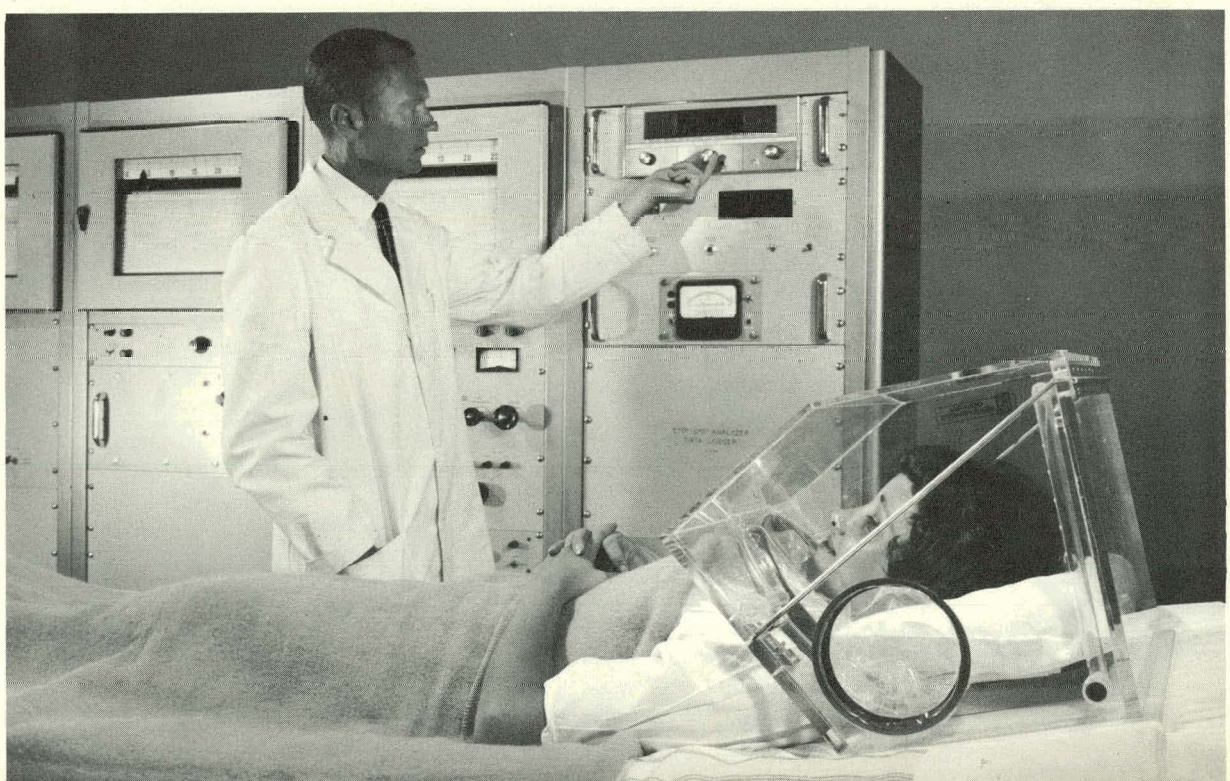
UTILIZATION OF GLUCOSE AND INTERMEDIATE CARBOHYDRATES IN DIABETES AND OBESITY

Further clinical studies of the simultaneous oxidation of glucose-1-C^{14} to $C^{14}O_2$ and of glucose-1-H^3 to H^3OH have been carried out by using the tracer technique. These studies show that obese patients with normal blood sugar but mildly diabetic according to glucose tolerance tests will manifest decreased carbohydrate oxidation under basal conditions as compared with nonobese, nondiabetic subjects. In addition, obese patients with very mild or preclinical diabetes show a definite decrease in the extent of oxidation of DL-lactate-2-C^{14} and pyruvate-2-C^{14} to $C^{14}O_2$, sometimes to one-half that of control subjects. Usually the rate of conversion of DL-lactate-2-H^3 to H^3OH is also depressed in diabetic patients, but results are less consistent than with C^{14}. The decrease in $C^{14}O_2$ from labeled lactate and pyruvate is found to be accompanied by greater than normal amounts of C^{14} converted to glucose and generally slower rates of disappearance of labeled lactate from the blood. These findings emphasize the importance of considering intermediary carbohydrate metabolism in the mechanisms of action of hormones involved in diabetes and obesity. The extent of the abnormalities in formation of $C^{14}O_2$ and H^3OH and the relative ease of measurement of these simple compounds give encouragement to the possibility that sensitive and practical clinical tests for the early or prediabetic state may be developed.

STUDIES OF THE RELATION OF CHEMICAL ATTACHMENT TO PHYSIOLOGIC ACTION OF NEUROHYPOPHYSEAL PEPTIDES ON MEMBRANE PHENOMENA

In order to obtain H^3-labeled neurohypophyseal peptides of increased specific activity, particularly for studies of subcellular sites of localization employing high-resolution radioautography, attempts to modify the Wilzbach procedure have been continued. In addition, a program of peptide synthesis has been initiated as an additional means of obtaining labeled peptides and for selected studies

Figure 9. Apparatus for continuous measurement of breath for C^{14} in expired carbon dioxide



of the relation of chemical structure to the affinity and intrinsic activity of antidiuretic hormone.

The interaction of tritium-labeled oxytocin with the rat kidney was investigated in order to get information about the chemical specificity of the antidiuretic action of mammalian neurohypophyseal hormones. Tritium-labeled oxytocin was prepared and injected into the renal arteries of ethanol-anesthetized rats in dosages ranging from 10^{-9} to 10^{-8} g. No antidiuretic action was noted in this dosage range, and no evidence of sulfur-sulfur linkage to renal tissue was observed after homogenization and treatment of washed labeled kidney sediments by methods that cleave SS bonds but do not disrupt peptide bonds (0.1 *M* cysteine, *p*H 8; 0.05 *M* sulfite in 6 *M* urea, *p*H 7). Control studies using H^3-lysine vasopressin showed SS linkage of hormone to tissue at all dosage levels, with direct correlation between binding and antidiuretic activity in the lower dosage range. These findings support the hypothesis that the formation of SS bridges between the neurohypophyseal peptides and kidney tissue represents a functional hormone-receptor interaction.

In a continuing collaboration with Dr. H. Rasmussen of the University of Wisconsin, an analysis of the effect on membrane permeability (in the toad bladder) of 35 analogues of arginine vasotocin was concluded. The data in conjunction with studies of the *p*H dependence of the response of the bladder to hormone also supported the suggestion that an SH-SS interchange reaction involving receptor SH and hormonal SS initiated the chain of events leading to the increase in membrane permeability.

In another series of studies, intrinsic and extrinsic factors that tend to diminish activity of the target organ (again the toad bladder) to hormone were identified and shown to be related to the history of previous hormonal challenge, particularly with respect to dosage, duration, and frequency. Studies have also been conducted in which changes in composition of the bathing medium were found to evoke reproducible changes in reactivity to hormone. These changes are attributed tentatively to alterations in the conformation of the receptor molecules.

BIOENERGETIC MECHANISMS INVOLVING FREE RADICALS

Ionizing radiations are known to produce free radicals in tissue, and much of the radiobiological

Electron paramagnetic resonance (EPR) spectrometry provides a means of identifying and describing free radicals with great sensitivity and specificity. It is a nondestructive technique based upon the magnetic properties of unpaired electrons, such as those of free radicals. These paramagnetic properties are not possessed by the usual diamagnetic organic molecules with paired electrons; thus EPR spectrometry can be used to study free radicals in the presence of other reactants, including the constituents of living cells.

Recent work here has resulted in improved reaction systems and experimental apparatus for eliciting EPR spectra from labile free radicals. Samples are retained in the liquid state to provide maximum spectral information regarding the electron configuration of free radicals, and constant-flow procedures are used to regenerate short-lived free radical products while EPR is recorded. Dead time between radical production and EPR has been reduced, and previous requirements for relatively large amounts of reacting materials have been lowered. As a result, EPR spectra have been elicited for the first time from free radical forms of biochemical compounds available only in small amounts, such as some hormones.

Data have been obtained describing free radicals from catecholamine hormones (epinephrine, norepinephrine, and synthetic analogues), indole hormones of animals (serotonin, adrenochrome) and plants (indole acetic and butyric acids), thyroid hormones and related analogues, estrogens (phenolic steroids, synthetic estrogenic substances), and from one protein hormone (insulin). Other preliminary investigations showing promise have used the EPR–constant-flow technique to simulate the chains of radiochemical reactions initiated by the action of ionizing radiation upon aqueous systems.

AUTORADIOGRAPHIC STUDIES OF GROWTH, AGING, AND REPAIR OF SKELETAL STRUCTURES

Tritiated thymidine was used in autoradiographic studies of the proliferative potential of the cellular complement of mouse incisors and the migration rate of ameloblasts in 5-wk-old female mice. Preameloblastic and preodontoblastic effect of such radiations is believed to result from further reactions of these radicals. The extent to which these effects are mediated by the free radical mechanisms that are intrinsic to life processes is unknown.

populations exhibited the highest labeling indices, 0.292 and 0.290, respectively. One hour after H^3-thymidine administration, no labeled ameloblasts or odontoblasts were observed. Labeling indices of pulp cells and fibroblasts in the periodontal membrane were small. The migration rate of ameloblastic cells, measured at intervals from 1 hr to 24 days, was found to be linear with time after 16 hr. A period of 24 hr appeared to be required for ameloblasts to complete proliferation and maturation and to reach the functional zone. The average migration rate of ameloblasts was 365 μ/day during the observation period of 24 days. Appearance of globular structures in the stratum intermedium and ameloblastic layer indicated degeneration of labeled ameloblasts 9 days after maturation. The average daily growth of the incisor was measured grossly (at 338 μ/day) and correlated with the migration rate of ameloblasts assessed microscopically (at 365 μ/day).

LYMPHOID CELLS IN THE DOG BONE MARROW AND BLOOD

The kinetics, origin, and fate of lymphoid cells in normal and irradiated dog bone marrow and blood were studied by the following method: Circulation arrest of one or both hind legs was achieved by clamping the femoral artery and vein. Immediately thereafter, H^3-thymidine (1 mCi/kg body weight) was injected into a front leg or sublingual vein. Serial smears for autoradiography were then made of venous blood and of bone marrow aspirated from different parts of the clamped leg (experimental marrow) and other parts of the skeleton (control marrow).

The following results were obtained for the nonirradiated dog: Heavily labeled leptochromatic lymphoid cells of medium and large size were found in the blood and control marrow within 15 min after H^3-thymidine injection and in the experimental marrow within 5 min after the release of the clamps. Heavily labeled small lymphoid cells began to appear in the experimental marrow at 2 to 3 hr post H^3-thymidine and reached a maximum on days 2 to 6. Their labeling indices (maximal values 15 to 20%), however, were significantly lower than those of the control marrow (maximal values 25 to 30%). After 7 hr, erythroblasts of all stages of maturation had a very low labeling index and mean grain count, whereas the latter was significantly higher in the control marrow up to day 3. On the other hand, the mean grain count of the erythroblasts of the experimental marrow was significantly lower than that of lymphoid cells during the first two days.

The data suggest that the dog bone marrow may contain two populations of small lymphoid cells, one originating from initially labeled precursors within the marrow (larger transitional cells?), the other immigrating from the blood. No evidence has been obtained that the lymphoid cells that have migrated can transform into hemopoietic cells within two days.

In comparison, the following results were obtained for the irradiated dog: Clamping and H^3-thymidine procedures were carried out during the early recovery phase (days 6 to 10) following whole-body x-irradiation with 250 R. At similar time intervals in both normal and irradiated dogs, labeled lymphoid cells were observed in the blood and in both the experimental and control marrows. In the irradiated dog, however, the labeling index of these cells exceeded 40% on day 1 following H^3-thymidine injection in the blood and in both marrows. During the first 24 hr labeled erythroblasts were found only in the control marrow. On subsequent days, however, the experimental marrow showed labeling in some unidentifiable blast-like cells. Although the high grain count of these cells largely excludes their labeling via DNA reutilization, it remains to be proved that transformation of labeled lymphoid cells into erythrocytic or myelocytic precursors has occurred.

LIFE CYCLE OF GRANULOCYTES IN MAN

In the continuing studies utilizing tritiated thymidine to characterize the life cycle of granulocytes in hematologically normal individuals and in patients with pathologically altered hematopoiesis, it has been clearly shown that the release of labeled granulocytes from the bone marrow is a random process and does not follow a "pipeline." It has also been demonstrated that there are two mechanisms by which granulocytes are lost from the blood stream. First there is a random loss from the blood at the epithelial surfaces of the body as demonstrated in oral lavage preparations. In addition, a proportion of the granulocytes undergo a 24 to 30-hr process of senescence and become pyknotic. This process of senescence truncates the random loss of granulocytes at $\approx$30 hr after their appearance in the peripheral blood.

In related studies on leukemic patients, tritiated cytidine is being used for *in vitro* labeling of the individuals' own cells. Upon autotransfusion of these cells, their disappearance rate from the peripheral blood and their appearance in the bone marrow are measured. Within 24 hr the fraction of labeled cells diminishes by a factor of 2. Thereafter, the intensity of the grain count and the fraction of the small to medium-sized lymphocyte cells that are labeled remains constant for a period >3 wk. Thus it appears that in chronic lymphocytic leukemia some of the newly formed cells have lifespans significantly in excess of 3 wk.

PREVENTION OF IRON ACCUMULATION IN AREGENERATIVE ANEMIA

As a part of studies on iron and vitamin B_{12} metabolism, the effect of anemia *per se* in iron absorption was investigated. A considerable number of anemic conditions are amenable to therapy only by blood transfusion. One of the many problems in treating patients with aregenerative anemia is the gradual, but incessant, increase of iron stores, brought about by the limited ability of the body to excrete iron. The iron that is administered as an integral part of the hemoglobin of the transfused blood is eventually stored in the liver, spleen, pancreas, and other organs and may then play a part in further deterioration of the patient's condition.

In recent experiments with animals made anemic by exposure to Sr^{89}, it was shown that anemia *per se* influences iron absorption. To determine whether this holds for human beings, seven patients with aregenerative anemia were given iron absorption tests when anemic, and when hemoglobin was maintained at normal levels with transfusions. The iron absorption procedures, using Fe^{59} and the whole-body gamma spectrometer, showed that in six of the patients iron absorption was significantly greater during the anemic period.

These studies point to a basic mechanism involving perhaps a humoral factor in iron absorption; or the results may reflect the response of the bowel to hypoxia.

Desferrioxamine *B*, a siderochrome chelating agent, will remove from the body 25 to 50 times the amount of iron normally excreted. The effect of this agent on excretion of Fe^{59}-labeled stores is under study. At present no curative agent for these disease states is known, but it is hoped that prevention of iron accumulation will prolong useful life beyond its present limits.

STUDIES OF PHYSIOLOGY OF TRACE METALS

The investigations of the physiology of some trace metals have led to the study of an extrapyramidal disease of man, chronic manganese poisoning. This disease, which often resembles the spontaneously occurring Parkinsonian syndrome, is found among miners who inhale manganese ores and is being studied under the joint sponsorship of Brookhaven National Laboratory, the National Institutes of Health, and the Pan-American Health Organization, by teams located at the Catholic University of Chile at Santiago and the Medical Research Center here.

The continuing studies on manganese have shown that (1) Manganese accumulates in mitochondria where it is essential to many steps of oxidative phosphorylation. (2) This metal stimulates the synthesis of cholesterol. (3) Its radioisotope, Mn^{54}, becomes incorporated in hemoglobin heme and can label a single generation of red cells *in vivo*. (4) Treatment of patients or animals with cortisone or some of its analogues induces significant losses of radiomanganese, so that manganese deficiency can no longer be considered as a hazard exclusively to grazing animals and chickens. (5) Chronic manganese poisoning is becoming recognized as a model for the study of human extrapyramidal disease. (6) Melanin granules (such as those lost from the brain in Parkinsonism and in phenylpyruvic oligophrenia) are loci of high accumulation of Mn^{54}.

Neutron activation analysis has shown that the metal's concentration in serum or blood is quite steady from patient to patient and from sample to sample. Its distribution among tissues is altered by surgical stress. Administration of prednisone induces a marked initial rise of plasma manganese, a marked redistribution among various tissues, and significant losses of metal into the feces. These findings support the earlier notion that manganese (and possibly other essential trace metals) is subject to homeostatic control.

Manganese is not excreted by the kidneys, but into the gastrointestinal tract. It was thought therefore that one of the tributaries to the gastrointestinal canal (i.e., biliary excretion) might function as a surrogate kidney in the homeostasis of manganese. Obstruction of the bile flow showed marked accumulation of manganese in the liver and probably also in the muscles of rats. Rats with biliary obstruction seem to lose their ability to regulate the excretion of the dietary manganese

absorbed from the gut. Sequential analyses of exteriorized rat bile indicated a striking dependence of the element's biliary excretion on the dietary supply of the element.

INTERRELATIONSHIP OF SODIUM AND GENETICS WITH HYPERTENSION

In the studies oriented toward the significance of the role of sodium in the pathogenesis of human hypertension, it has been observed repeatedly, markedly in their response to salt: one strain, the so-called Sensitive Strain, rapidly develops severe and fatal hypertension from a salt intake to which the other, the so-called Resistant Strain, responds hardly at all. Similar variations in genetic sensitivity to salt in man would explain, at least in part, the observed fact that whereas some human beings are remarkably responsive to increments and decrements of salt, others are notably unresponsive.

Despite the fact that salt consumption precipitates hypertension in rats of the Sensitive Strain,

Figure 10. Measurement of blood pressure in rats made hypertensive by salt feeding.

in both man and rats, that some individuals failed to develop hypertension despite life-long high salt intakes. In contrast, at least in the experiments with rats, some animals died of fulminating hypertension a few months after commencing high salt diets. These marked variations in response to similar amounts of the same agent suggested that differences in genetic constitution were involved. During the last four years this possibility has been explored with the technique of selective inbreeding. Two strains of rats have been evolved that differ the subsequent restriction of salt more often than not fails to cause a fall in blood pressure. Furthermore, recent studies have failed to reveal increased sodium in the tissues of these salt-fed hypertensive rats as evidenced (1) by carcass analysis, (2) by total exchangeable sodium (measured with either Na^{22} or Na^{24}), or (3) by differences in the biological half-life of Na^{22} in animals with and without hypertension. Thus, while a high salt intake may initiate the hypertensive process, continuation of this salt intake is not required for maintenance of

hypertension, and there is no evidence of gross accumulation of sodium in the hypertensive animal. Furthermore, a number of hypertensive human beings who did not have a prolonged biological half-life for Na^{22} have now been observed. This study was an extension of earlier studies in man in which a statistically significant increase in the biological half-life of Na^{22} among hypertensive subjects was observed. The exceptions found recently suggest that such an increase is not a necessary correlate of the disease, and this finding is in keeping with the observation in rats.

In patients with hypertension, vascular hyperreactivity is usually present, but it has always been uncertain whether this preceded or followed the disease. If it preceded the onset of frank hypertension, this could play an important role in the development of the high blood pressure. Normotensive rats of the Sensitive Strain have shown an increased blood pressure response to vasoconstrictor agents before salt feeding as compared with animals of the Resistant Strain. It seems probable that innate vascular hyperreactivity is part of the genetic component that characterizes those rats destined to become hypertensive and that this may have a bearing on the process of essential hypertension in man.

MEDICAL STUDIES OF THE PEOPLE OF THE MARSHALL ISLANDS ACCIDENTALLY EXPOSED TO FALLOUT

Annual medical surveys are carried out on the people of the Marshall Islands who were accidentally exposed to fallout in March 1954. Considerable knowledge of the effects of fallout radiation on human beings has been gained from these studies, which are conducted under the auspices of the Division of Biology and Medicine of the U.S. Atomic Energy Commission and under the direction of the BNL Medical Department, with the assistance of medical and technical personnel from the Trust Territory of the Pacific Islands. Gamma radiation with hemopoietic depression was the most serious consequence of the exposure; beta burns of the skin, although partly disabling, were less serious; and internal absorption of radioisotopes appeared to be the least serious of the hazards. Other findings over the past 10 years include: (a) The gamma radiation (highest dose, 175 rads) does not appear to have been related directly to the deaths, illnesses, or diseases that have occurred. (b) The marked depression of peripheral white blood cells and platelet levels that occurred early was followed by rapid increase during the ensuing months, but a slight deficit still persists in the mean levels of these elements compared with levels in the unexposed population. (c) Growth and development studies have shown a slight retardation in the exposed children, particularly in males exposed between 15 and 18 months of age. (d) Studies of late effects, such as leukemia, premature aging, cataracts, and genetic effects, have had largely negative results, although some of the exposed women had an increased incidence of miscarriages and stillbirths during the first few years after exposure. (e) Development of thyroid nodules in three exposed teenage girls (not seen in nonexposed girls) is being investigated. (f) Beta burns of the skin healed within a few months, and in persons with epilation hair regrew by six months. A few skin residua persist in some people in the form of scarring and pigment aberrations but with no indication of malignant changes. (g) Radioisotopes absorbed internally were rapidly eliminated during the first few years, but since the return of the people to Rongelap (1957) low but detectable levels of Cs^{137}, Zn^{65}, and Sr^{90} have been present in both the exposed and unexposed groups as a result of low-level contamination of the island plant and marine life.

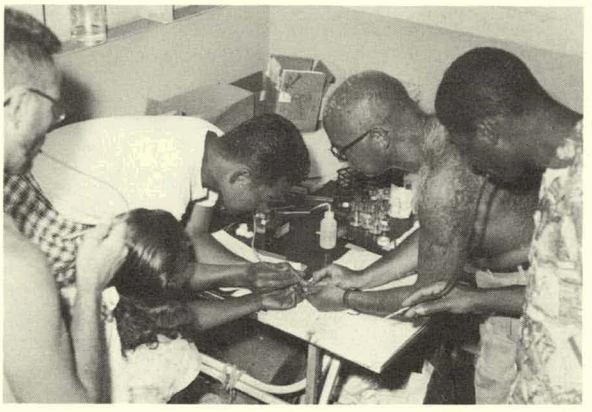


Figure 11. Survey personnel examining Marshallese.

In the 1964 survey peripheral blood and skin cultures from irradiated individuals were obtained on Rongelap Island, and the samples were brought to this Laboratory for cytological studies on the effects of ionizing radiation in producing alterations in numbers and aberrations of chromosomes. Initial observations indicate that certain aberrations are present.

SUPPORTING ACTIVITIES

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

Technical Operations and Services

The technical services and facilities essential to the Laboratory's research programs are provided by a number of organizational units whose operations are described below under appropriate headings.

REACTOR OPERATIONS

The Brookhaven Graphite Research Reactor (BGRR) continued its record of reliable performance by operating throughout the year without a major operating incident. Full power operation was maintained for 84.6% of the year. There were 19 scheduled shutdowns for service and maintenance of the reactor and experimental equipment. Four shutdowns were scheduled on short notice for inspection or correction of operational difficulties. A total of 15 shutdowns of short duration occurred without notice. Six of these were caused by interruptions in electrical power, and the remainder were due to equipment malfunctions or human error. This unusually high incidence of unplanned outages is attributed to "shakedown" of new instrument systems installed during the year and to the heavy training requirements entailed in staffing the High Flux Beam Research Reactor (HFBR).

The practice of frequently annealing the graphite structure of the reactor was continued throughout the year. Annealing operations were conducted on a routine basis following 18 scheduled shutdowns. Periodic measurements of growth recovery indicate that the annealing program is effectively reducing the net vertical displacement of the center of the graphite structure.

During the annual Christmas-holiday shutdown, several inspections and tests were conducted in areas that usually are of limited accessibility. The emergency diagonal shot wells were satisfactorily tested; the area of the central air gap in which broken graphite bars had protruded last year was inspected, and the bars were found to be in their correct positions; and the exit air filters were tested with dioctyl phthalate aerosol to confirm their satisfactory performance.

During the long holiday shutdown, work was largely completed on a program to optimize the distribution of cooling air flow through the fuel channels by adjusting the size of orifice disks attached to individual fuel channel anchors. This program, undertaken to reduce the cost of cooling the reactor, appears to have been quite successful. A computer program prepared as part of this project will be used in periodic reappraisals of air flow distribution.

In May, excavation was begun for installation of a bypass exit-air filter facility to provide for fission product removal from the effluent in the unlikely event of a major accident. The HFBR will also be serviced by this facility.

Improvements in the instrumentation of the BGRR, part of a long-term program, were essentially completed with the installation of a new fuel-temperature limiting system. This system, of unique design, combines rate of change signals with signals proportional to actual temperatures to produce a trip condition that anticipates a preset maximum temperature. A 2-out-of-3 logic system permits testing and maintenance of individual channels while the reactor is in operation.

The training program for personnel hired to staff the HFBR continued throughout the year, culminating in the qualification of the last 7 of the 15 trainees as operators of the BGRR. With completion of the program, a staff of experienced operators is available for initial operation of the HFBR and qualified crews can be maintained at the BGRR.

As in the past years, several audits of the various activities of the Reactor Division were conducted by representatives of the AEC, the Division of Reactor Safeguards of the International Atomic Energy Agency, the BNL Audit Group, and the *ad hoc* committees regularly appointed by the Laboratory's Director. The results of these inspections were generally favorable.

Utilization of the Graphite Research Reactor

Figure 1 illustrates the continued downward trend in operating expense at the BGRR; total operating costs have dropped consistently over the past four years. However, the charges to the users depend not only on operating costs but also on total utilization of the reactor.

During the year a third 4-in.-diam vertical hole was drilled in the moderator structure (most of the experimental holes are horizontal). Such additional and improved irradiation facilities are desirable to offset the loss of use charges from completed experiments and experiments that may be relocated at the HFBR when that reactor becomes operational.

The use of the BGRR and the associated charges for the last three years are summarized in Table 1. Approximately 35 experimental holes continued to be assigned to research departments of the Laboratory. Projects under way at these facilities are described in the appropriate sections of this report. The number of controlled temperature facilities and of experimental holes assigned to the graphite monitoring program and the average number of facilities occupied by outside users remained at last year's level, i.e., 8, 5, and 4, respectively. Brief descriptions of the activities of outside users are given below.

Columbia University. Studies of atomic motion in gases, liquids, and solids were performed with a single-crystal neutron spectrometer having an effective neutron energy range from 0.0006 to 10 eV. Investigations of fission-fragment mass distributions in binary fission and alpha-particle energy distributions in ternary fission were continued. The fission products were detected with solid-state devices.

Two techniques for producing intense beams of low energy neutrons, which are essentially free from fast neutrons and gamma rays, were investigated and developed for future use at the HFBR.

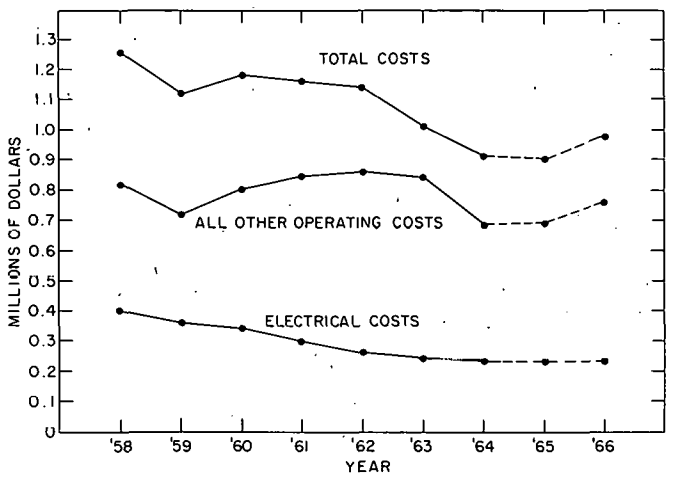


Figure 1. Costs connected with operating the BGRR.

In the first method, neutrons are conducted by total reflection through long, curved beam tubes; in the second, fast neutrons and gamma rays are removed from the reactor beam by single-crystal filters which are cooled to liquid nitrogen temperatures.

Naval Ordnance Laboratory. In cooperation with the BNL Physics Department (Solid State Division), diffraction studies were made by using single crystals and a polarized beam of neutrons. In addition, powdered magnetic materials were studied with use of a powder diffractometer.

Brown University. Metallurgical specimens of aluminum and copper were irradiated to study radiation damage. Some interesting effects were found in the irradiated copper specimens. Short-term irradiation of several types of alkali halide crystals has been carried out to study radiation damage versus thermal neutron dosage.

Rensselaer Polytechnic Institute. A circulating gas loop experiment is in progress to study the effects of various parameters (temperature, pressure, and gas composition) on the production of NO_2 from oxygen-nitrogen mixtures using fission fragment energy. The high-pressure stainless steel loop contains uranium-bearing glass wool (total U^{235}, 1.5 g). Nitrous oxide is being used as the dosimeter.

A second in-core loop has been installed recently in a reflector channel. It is the same as the first loop except that it contains no uranium. Data from capsule irradiations indicate that much interesting information can be obtained without the presence of uranium. In this loop the energy deposition in the process gases is due only to neutrons and gamma rays from the reactor.

In addition, static tests were carried out by irradiating sealed quartz ampules containing various gaseous mixtures, with and without uranium, at different temperatures and different pressures.

Naval Research Laboratory. Long-term irradiation is in progress of special alloy specimens at reactor ambient temperature. Upon removal from the reactor the specimens will be returned to NRL for an evaluation of radiation damage effects.

Bell Telephone Laboratories. Studies have been successfully made of the magnetic and crystal structures of KRe, T_2O_3, V_2O_3, and hübnerite at liquid helium temperatures.

General Electric Company. During fiscal 1964 the General Electric neutron spectrometer was used for investigation of (1) the magnetic structures of manganese alloys of composition Mn_3X,

Table 1

Summary of Reactor Use Charges

	Use charges (in thousands of dollars) 0 100 200 300 400 500 600 700	Percent of total usage	Dollar amounts
Fiscal 1964			
Outside Organizations		9.0	$ 108,952
Irradiation Service Group		4.0	40,992
BNL Research Departments			
Physics		60.0	647,930
Chemistry		8.0	94,620
Nuclear Engineering		15.0	169,100
Biology		4.0	40,860
		100.0	$1,102,454
Fiscal 1963			
Outside Organizations		9.5	$ 100,996
Irradiation Service Group		3.1	40,992
BNL Research Departments			
Physics		58.9	688,002
Chemistry		9.8	110,520
Nuclear Engineering		15.6	182,927
Biology		3.1	40,860
		100.0	$1,164,297
Fiscal 1962			
Outside Organizations		5.7	$ 65,156
Irradiation Service Group		4.6	51,739
BNL Research Departments			
Physics		63.2	724,096
Chemistry		9.7	111,870
Nuclear Engineering		13.0	149,008
Biology		3.8	43,500
		100.0	$1,145,369

where X=Sn, Ge, or Rh (a continuation); (2) the *A-A* interaction in spinels Co_3O_4, $CoAl_2O_4$, and $FeAl_2O_4$; and (3) the structure of calcia-stabilized zirconia, $Ca_xZr_{1-x}O_{2-x}$, with $0.13<x<0.19$.

Irradiation Services and Isotope Production

Table 2 presents a summary of the volume and income involved in providing irradiation services to outside organizations over the past three years. There has been a continuing but smaller decrease in reactor irradiations during the past year. This trend is expected to continue, in line with the AEC's policy of noncompetition and the increasing availability of similar services in commercial reactors. The number of processed radioisotopes, however, has continued to increase, since these are of a specialized nature and are not yet commercially available.

Last year it was noted that the volume of irradiation services in terms of reactor usage appeared to be leveling off, and this forecast was borne out during fiscal 1964. The increased pressure by the AEC for noncompetition with commercial reactor facilities makes future volume uncertain.

The distribution of the services covered in Table 2 is presented by type of customer in Table 3. No significant or marked changes are apparent.

Table 2

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

	Fiscal 1964		Fiscal 1963		Fiscal 1962	
	Number	Volume, $	Number	Volume, $	Number	Volume, $
Reactor irradiations	453	52,209	466	55,196	641	75,918
Processed radioisotopes	441	72,032	376	72,726	349	59,926
Co^{60} sources	3	4,158	4	19,442	3	3,077
Cyclotron irradiations	3	580	8	2,095	12	2,342
Total	900	128,979	854	149,459	1,005	141,263

Table 3

Types of Customers Receiving Shipments

	Fiscal 1964		Fiscal 1963		Fiscal 1962	
	% of Customers	% of Shipments	% of Customers	% of Shipments	% of Customers	% of Shipments
Hospitals	26	40	25	39	22	51
Industrial	38	30	35	22	36	24
Universities	25	21	27	34	26	19
Government	4	3	5	1	8	3
Foreign	7	6	8	4	8	3

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, 325 purchase orders were placed for radioisotopes, 47 for stable isotopes, and 74 for special materials. Against these orders ≈600 shipments were received and processed. These figures represent an increase over last fiscal year of 8% in orders placed and 3% in receipts. Of the orders placed, ≈33% were for the Medical Department, 21% for Biology, 16% for Chemistry, 14% for Nuclear Engineering, 11% for Physics, 1% for Instrumentation and Health Physics, and 4% for the Reactor Division.

The Isotopes and Special Materials Group is responsible also for annual inventories of radium sources and purchased stable isotopes and for negotiations for the loan of valuable isotopes. The number of radium sources at Brookhaven was essentially unchanged at 38 with a total activity of 5.86 curies and a value of ≈$39,495. The year-end inventory of purchased stable isotopes ($22,900) was much smaller than last year's ($32,900), since consumption during the year ($17,700) exceeded new purchases ($7700). The stable isotopes loan agreements continued to decrease, going from 39 to 33 in number and from $180,000 to $129,000 in value, exclusive of 5 special samples valued at $1.28 million.

The Brookhaven irradiation programs in the Materials Testing Reactor (MTR) and Engineering Test Reactor (ETR) are summarized below.

BNL-28: Radiation Damage in Carbon. This program was a continuation of previous programs BNL-19, 23, and 24. The irradiation of two capsules containing diamond chips was completed and the program was terminated in October 1963.

BNL-29: Settled Bed Reactor Fuel Test Program. This program, approved in February 1964, provides initially for irradiation of two instrumented capsules containing a 10% enriched uranium-bearing fuel in liquid metal. Actual irradiation is expected to begin early next fiscal year.

BNL-30: Neutron Irradiation Burnup Studies on Chemonuclear Fuel Materials. This program was approved in February 1964 as a continuation of the BNL-26 program. Seven capsules containing

uranium-bearing samples have been irradiated, and the program will be terminated early in fiscal 1965.

BNL-31: Radiation Damage in Pure Iron, Iron Alloys, and Pure Niobium. This program, approved in June 1964, provides for the irradiation of two capsules containing several iron and niobium tensile test specimens. The program is expected to be completed by the middle of fiscal 1965.

Source and Special Nuclear Materials Accountability

Table 4 presents a 3-year summary of the amounts of source and special (SS) nuclear materials on hand at Brookhaven at the end of each fiscal year. Based on dollar values published by the AEC, the current inventory of SS materials represents a value of ≈$8.6 million. The net increase from last year's estimated value of $6.6 million was due primarily to the large amount of U^{233} received during the year.

As mentioned in last year's report, an order was placed for 1400 BGRR fuel elements. Because of many difficulties in fabrication, the vendor was able to deliver only 457 finished fuel elements. Since this vendor is located on the West Coast, frequent inspection trips and close surveillance by Brookhaven personnel were not possible.

Table 4

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

	Fiscal year		
	1964	1963	1962
Station BRL			
Natural U	1,701	1,720	2,043
Depleted U	763	669	2,968
$U^{235}>75\%$	212	211	142
$U^{235}<75\%$	6,342	6,412	6,410
U^{233}	23	0.047	0.027
Pu^{239}	2	2	3
Th	942	204	216
Heavy water	54,430	53,591	15,030
Station BRG (Graphite Reactor Fuel)			
$U^{235}>75\%$	82	99	108
Station BRM			
$U^{235}>75\%$	3	3	3

An order was placed for 140 HFBR fuel elements with a fabricator in New Haven, Conn., a location that made it possible to follow the work closely, even to the extent of taking gamma-counting equipment to the fabricator's plant for inspection purposes. As a result of this close surveillance, some problem areas were uncovered and rectified.

The gamma-counting equipment referred to above was acquired for use in nondestructive verification of U^{235} content. It was initially used for inspection of the two fuel element orders, but it is also intended for general use, where applicable, in verification of inventory items and receipts and removals made under the SS Accountability System. The availability of this equipment for nondestructive assays supplements the destructive facilities available through the Chemistry and Nuclear Engineering Departments and the AEC's New Brunswick Area Office. The use of these facilities under the SS Accountability System is to be summarized in an SS Material Measurement Program in accordance with AEC requirements.

As part of an AEC requirement and for general Laboratory use, a revision of the *Special Nuclear Materials Manual* was issued in February 1964 covering the specific rules and procedures for the handling of fissile materials at Brookhaven, primarily from the aspect of nuclear safety.

Continuing effort was directed toward reduction of the SS material inventories through removal of surplus items and disposal of scrap. This year ≈7 kg of natural uranium and 4 kg of thorium were removed, and an additional 5 kg of enriched U^{235}, 1124 kg of natural uranium, and 115 kg of thorium are scheduled for removal early in fiscal 1965. Shipment of spent BGRR fuel elements continued during the year, with 9 shipments containing 1512 elements being made to the Phillips Petroleum Chemical Processing Plant at Idaho Falls, Idaho.

Under the Four Reactors Agreement with the U.S. Government, effective June 1, 1962, the International Atomic Energy Agency (IAEA) performed two inspections this year, the fourth and fifth under the agreement. The first was made from November 12 to 15, 1963, by three inspectors, Mr. Carlos Buchler, Mr. Juan Eibenschultz, and Dr. Robert Skjoeldebrand. They were accompanied by two consultants from AEC Headquarters, Mr. James Herring and Mr. Russell Weber, who advised them on formal auditing procedures. During this inspection the IAEA selected a spent BGRR fuel plate to be sent to their laboratory in

Europe for destructive analysis as verification of the reactor burnup calculations. This plate was packaged by BNL for shipment, but, because of contractural delays between the IAEA and the U.S. Department of State, shipment has not yet been made.

The second inspection was made from April 23 to 27, 1964, by Mr. Buchler and Dr. Skjoeldebrand. Both inspections involved auditing of the SS material inventories and of accounting and operating records for evidence of diversion, and review of facility usage in terms of peaceful purposes. The results of these inspections were satisfactory. The U.S. Government Agreement with the IAEA, which originally was to expire on June 1, 1964, has been extended for an additional five years.

Medical Research Reactor

The Medical Research Reactor (MRR) was operated on 286 occasions during the year, and 586,542 kWh of operation were accumulated. The total integrated energy to date is 2,009,508 kWh. Figure 2 illustrates the use of the reactor during the last five years, expressed in terms of the number of reactor runs and integrated power accumulated per year. Epithermal neutron irradiation studies, utilizing the animal treatment facility for phantom and animal irradiations, are continuing. Other experimental programs being conducted are concerned with the effects of ionizing radiation on tree seedlings, the application of neutron radiography to biological materials, and thermal neutron irradiation of bacteria. The pneumatic tube facility is being used in many neutron activation analysis studies.

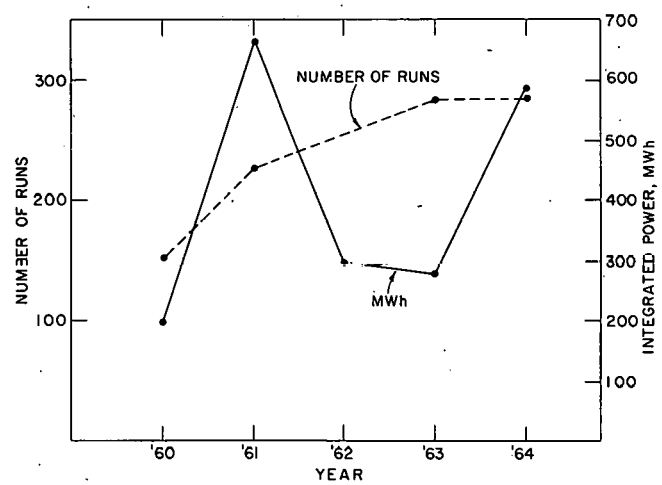


Figure 2. Use of the MRR.

Replacement of the aluminum tubes in the MRR heat exchangers with stainless steel tubes has resolved the problem of heat exchanger leaks. The heat transfer area of the stainless steel tube bundles was increased to prevent any significant change in reactor operating temperatures.

Improvements in the system of locks and interlocks on access doors to potentially hazardous areas in the MRR have removed the possibility of accidental overexposure of persons unfamiliar with the facility. The console operator is now provided with indicators informing him of the position of shielding devices, and he can take appropriate action when hazardous areas are inadvertently entered during operation.

Minor swelling of one of the reactor control rods was discovered during a routine semiannual inspection in October 1963. Since no evidence of a leak in the control-rod envelope was found, it was concluded that the mechanical seal had allowed a small amount of water to enter the rod. Studies conducted with a solid, borated, stainless steel material have shown this material to be suitable for use as control rods, and fabrication of solid rods to replace the present rods was in progress at the end of the year.

Increased usage of the pneumatic tube facility for activation of biological samples has resulted in a sharp increase in total integrated energy over the past year. The reactor core loading has been increased to 20 BSF-type fuel elements in order to maintain sufficient excess reactivity so that fission product poisoning will not prevent consecutive daily start-ups of the MRR. Central-element fuel burnup is still $<5\%$, and discharge of fuel elements because of burnup is not yet being considered.

An in-place efficiency test of the absolute type of reflector exhaust-air filter bank was conducted in January. A polydisperse dioctyl phthalate aerosol (average particle size, $\approx 0.8\ \mu$) was introduced into the air exhaust system, and relative aerosol concentrations were measured upstream and downstream from the filter bank by means of a Sinclair-Phoenix light-scattering photometer. Results indicate the efficiency of the filter installation to be $\approx 99.9\%$.

HEALTH PHYSICS

Service activities of the Health Physics Division, which include general safety, waste disposal, and

reclamation functions as well as radiation protection, continued at about the same level as last year. The scale of monitoring duties at the Alternating Gradient Synchrotron (AGS) increased markedly as a result of increasing levels of operation and completion of the new neutrino facility. Considerable effort was devoted to radiation safety aspects of the design of the tandem Van de Graaff accelerator and the Biology Department's controlled environment laboratory in collaboration with the scientific groups concerned. These projects, as well as a proposed 12,000-Ci irradiation facility planned for the Physics Department, were reviewed by the Laboratory Safety Committee. A revised edition of the *BNL Safety Manual* was issued in the fall of 1963.

Facilities for in-place testing of filters used for air cleaning in various parts of the Laboratory were completed, and tests were carried out on the filters at the shotblasting facility, the BGRR, and the MRR. A Tri-Carb scintillation counting system for urinalysis and assay of environmental samples for tritium was procured to meet the problems expected when the HFBR goes into operation next year. Other items of capital equipment obtained during the year were a new densitometer for personnel monitoring, a spectrum plotter for the gamma spectrometer, and a fluorimeter for use in uranium urinalysis.

Personnel Monitoring

Regular personnel monitoring service was provided for 2835 individuals during calendar 1963, a 13% increase over 1962. Film dosimeters were provided for $\approx$7200 visitors. A key punch was obtained so that quarterly and annual exposure data for all individuals can be recorded on Remington Rand cards by the Personnel Monitoring staff for processing and tabulation by the Data Processing Center of the Fiscal Division.

The distribution of exposures for the 2835 individuals regularly monitored is shown in Table 5. There was a substantial decrease in the higher exposures; only 17 were $>$2.5 Rem, as compared with 41 in 1962. All exposures were $<$3 Rem per 13-wk period, and in no case was the prescribed limit on integrated exposures exceeded.

Radioactive Waste Disposal and Reclamation

The first shipment of waste disposal vaults was sent to the newly opened N.Y. State burial area for radioactive wastes at West Valley, N.Y. Packaging procedures have been adjusted so that all vaults now meet ICC requirements for rail shipment. A 1-yr accumulation of 38 vaults weighing 330 tons and containing $\approx$75 Ci of activity was shipped.

Disposal of large contaminated items, such as tanks, was greatly facilitated by the use of formed explosive charges. This technique makes it possible to cut up such objects with a minimum spread of contamination. Usually they can then be decontaminated with the shotblaster and taken to the Laboratory dump.

The capacity for distillation of reclaimed mercury from contaminated was doubled to keep up with demand. A total of 3900 lb was returned to stock during the year.

Data relating to the liquid waste system are presented in Table 6. The amount of activity leaving the site in the stream to which the effluent is discharged totaled 89 mCi during the fiscal year, and the average concentration was 8.3×10^{-8} μCi/cc, which is 17% of the applicable off-site drinking water limit. The activity in the cooling-air effluent from the BGRR was relatively constant, with an average discharge rate of 16,000 Ci of Ar^{41} and 0.0062 Ci of I^{131} per day.

Synchrotron Monitoring and Dosimetry

Control of exposures at the AGS requires considerable effort by all concerned. Beam intensities

Table 5

Distribution of Exposures of Individuals Receiving Regular Personnel Monitoring Service

Exposure index range*	Calendar 1963	Calendar 1962
0.00–0.49	2572	2330
0.50–0.99	149	79
1.00–1.49	58	30
1.50–1.99	25	13
2.00–2.49	14	11
2.50–2.99	8	14
3.00–3.49	3	8
3.50–3.99	1	5
4.00–4.99	4	6
5.00–5.99	1	7
6.00–6.99	0	1
Total	2835	2504

*Exposure index = ½ of β exposure in rads + γ exposure in R + neutron exposure in Rem.

Table 6

Summary of Liquid Waste Data

	Fiscal 1964	Fiscal 1963
Input to filter beds, gal/day	844,000	720,000
Output from filter beds, gal/day	666,000	578,000
Net loss in filter beds, %	21.2	19.5
Stream above discharge point, gal/day	74,000	121,000
Stream at site boundary, gal/day	775,000	661,000
Rainfall, in./mo	3.0	3.5
Activity concentration at input to filter beds, Ci/cc	1.0×10^{-13}	1.4×10^{-13}
Activity concentration at output from filter beds, Ci/cc	1.0×10^{-13}	1.3×10^{-13}
Activity concentration at site boundary, Ci/cc	0.83×10^{-13}	1.1×10^{-13}
Activity at input to filter beds, mCi/mo	9.7	10.6
Activity at output from filter beds, mCi/mo	7.8	8.8
Activity at site boundary, mCi/mo	7.4	8.1

Figures are averages for each fiscal year.

have increased to the extent that there is substantial activation of machine components, and work inside the synchrotron enclosure during shutdowns must be carefully controlled. This problem will become even more acute in the future as additional increases in intensity are made.

Very extensive measurements of radiation levels, both within the buildings of the AGS complex and in the surrounding area for distances of half a mile, were carried out as a basis for forecasting conditions to be expected for the greatly increased machine intensities that may result from improvements being considered for the future.

A Hankins-type neutron monitor has been acquired for determining neutron dose rates directly in Rem/hr at the synchrotrons. Some additional data have been obtained on the variation of dose with depth in a phantom. A new vacuum system for use with the Rossi-type linear energy transfer (LET) chamber has been acquired, and a series of determinations of the distribution of dose with LET for a variety of locations is planned for the fall of 1964.

Environmental Monitoring

Background radiation dose rates measured with an ionization chamber mounted 6 in. above the roof of an off-site station averaged 5.6 mR/wk during the last half of 1963. On January 1, 1964, the chamber was mounted 2 ft above the roof so as to yield values comparable to those 3 ft above the ground, a location often used elsewhere for background monitoring. Values for the first half of 1964 averaged 3.0 mR/wk, which is roughly ⅔ of what would have been obtained with the previous chamber location. The background dose rate in a typical frame house was found to be $\approx$2 mR/wk.

The average fallout rate in rain and settled dust was 155 mCi/sq mile/mo as compared with 488 mCi/sq mile/mo last year. The rate varied considerably from month to month, with a maximum value of 470 mCi/sq mile/mo during July.

The highest radiation level at the site boundary occurred at a point opposite the gamma forest source and averaged 7.0 mR/wk. This may be broken down into 3 components of 4.5, 0.9, and 1.6 mR/wk due to background, Ar^{41} from the BGRR, and the forest source, respectively. Thus, the total addition to background due to Laboratory operations was 2.5 mR/wk, which may be compared with the permissible level of 10 mR/wk.

General Safety

The general safety program continued to emphasize prevention of the catastrophic, more severe type of accident, while at the same time controlling the less serious, ordinary accidents. As in the past several years, the injury frequency rate for calendar 1963 was maintained below 4.0, with accident costs decreasing to the average for clerical employees in New York State.

Liquid hydrogen safety research, conducted under contract, included a theoretical study of the ability of various configurations of bubble-chamber blockhouses to withstand maximum credible explosions.

Consulting services were provided to design engineers in connection with the fire and safety aspects of a number of new projects. Several new fire and safety standards were established for Laboratory-wide application.

Inspection activities included on-site construction projects as well as those conducted in cooperation with the Laboratory's operating departments. Each of the *ad hoc* safety committees established by the various operating departments to review the hazards of proposed experiments was assisted by an ex-officio member from the Division's Safety Services Office.

Table 7

Assignment of Mechanical Engineering Division Personnel as of June 30, 1964

	Engineers	Designers and draftsmen	Secretarial and clerical
Accelerators			
AGS	24	24	2
Cosmotron	10	7	–
Central Design	1	8	1
Nuclear Engineering	6	21	1
Physics			
Bubble chambers	15	13	–
General design	9	19	–
Safety Services	1	–	–
Total	66	92	4

Total personnel – 162

MECHANICAL ENGINEERING

This past year the number of full-time personnel in the Mechanical Engineering Division increased from 146 to 162. The distribution of personnel among the various BNL departments is shown in Table 7.

Division personnel assigned to the Cosmotron continued to support the experimental program and the development of new equipment for the accelerator. Three internal target rams were developed to make possible remote positioning and ramming of a target to any machine radius. One ram (for radiochemistry experiments) has built-in detection apparatus with which a target can be exposed, removed from the beam, calibrated and counted, and returned to its original position within the 2.5-sec repetition rate of the Cosmotron. A hydraulic ramming system has been designed to insert the ejection magnets after injection and so increase the injection aperture.

The main Cosmotron magnet cooling system which was based on water cooling towers has been replaced by a closed system utilizing a heat exchanger cooled by water from the Laboratory's system. Because of the lower temperature of the Laboratory water the magnet coil temperature has been reduced to 90°F, and this has lowered the ambient temperature in the magnet shielding tunnel. To reduce the use of Laboratory water, a 36-MW cooling tower has been put into operation to cool beam transport magnets, which can operate at higher temperatures. A central control room was constructed for all mechanical systems.

A combination beam pipe and beam plug has been developed to be placed in external beams. It can be evacuated for beam traversal or filled with water to serve as a beam stopper. It is planned to install this system in the three external beams. The Division's liaison engineers have assisted in the layout, construction, and operation of various experimental arrays during the past year. Among these was a liquid nitrogen supply system for a high-field pulsed magnet with a peak evaporation rate of 800 liters/hr. Three experiments utilized heavy beam transport magnets in an array which, mounted on a roller table, could be accurately traversed through an arc.

Engineers of this group supervised the operation of the heavy water electrolysis plant, which produced 110,000 ft^3 of deuterium gas, and the liquid hydrogen facility, which distributed 100,000 gal of liquid hydrogen.

Technical assistance was given the Purchasing Division in the selection of a liquid hydrogen vendor and a liquid nitrogen vendor and also to the Architectural Planning Division in the selection of equipment and preparation of the site for a 14,000-gal liquid hydrogen storage facility.

A major effort of Division members at the Cosmotron has been the design, fabrication, and operation of 11 targets for use with liquid hydrogen or liquid deuterium at the Cosmotron and 12 at the AGS. These targets consist of a Mylar target vessel surrounded by a vacuum vessel and superinsulation. Auxiliary equipment includes a liquid hydrogen reservoir, a liquid level indicator for the target and reservoir, a vacuum-insulated transfer line, and vapor vent lines.

In addition, three special targets were fabricated and arranged to operate side by side on a carriage and rail system. Each target has an inner envelope with 6-in.-diam by 120-in.-long working dimensions, surrounded by a concentric container wrapped with superinsulation. In operation one target is filled with liquid deuterium surrounded by liquid hydrogen, the next has liquid hydrogen in both chambers, and the last has its inner chamber evacuated and the outer filled with liquid hydrogen. Thus, by moving the targets on the track, difference measurements can be easily taken to determine the effect of the target material, liquid hydrogen, and liquid deuterium.

Two of these targets were later modified to include a larger (400-liter) reservoir to reduce the

number of fillings necessary and thus keep the temperature and density of the liquid in the target constant to 1 part in 10,000.

At the AGS three short beam separators, each 6.5 ft long, were designed for use in the low energy separated beam. They offer the possibility of installing two stages of separation instead of one in the available space. These units were designed with an aluminum vacuum chamber and a non-integral iron core magnet, which eliminated most of the difficult fabrication problems encountered in previous designs. All parts are on hand, one unit has been assembled, and magnet tests are under way.

Three rf beam separators of the iris waveguide type are on order. The first experimental cavity, delivered late last year, has been tested to evaluate its electrical and mechanical accuracy. On the basis of these test results a 1-m prototype separator structure has been delivered. Electrical tests and measurements are now being made on this prototype and have progressed to the extent that three full-sized 3-m-long cavities have been ordered.

The first eight drift tubes of the AGS linac have been redesigned to increase beam intensity. The diameter of the bore tube has been enlarged from 0.5 to 0.75 in. Machining of drift tubes, quadrupoles, and associated hardware is complete, and final fabrication and assembly are in progress.

Work is continuing on the fabrication and installation of a pulsed momentum analyzing system to continuously monitor the linac beam for energy and energy spread. The system consists of a pulsed deflecting magnet, focusing quadrupoles, slit boxes, viewing boxes, an analyzer magnet, and a Faraday cup in which the analysis is made.

The central tube and vacuum seals in the rf cavities have been redesigned to eliminate some operational problems. New ceramics are on hand and new hardware is on order. Conversion is expected to take place one cavity at a time during the coming year.

Work is continuing on the fabrication and assembly of a large-aperture bending magnet. The magnet is 3 ft long with a 2-ft-high by 10-ft-wide aperture. The weight of the core is 300,000 lb and of the copper 20,000 lb. The design field is 15 kG, and the magnet is designed to translate 6 ft and rotate 40°, the movement being achieved hydraulically by using flat hydrostatic bearings.

Design of a special "C" deflecting magnet with a field of 15 kG for use on a low energy separated beam at the AGS is now complete. This magnet can be mounted close to the synchrotron orbit, which allows the separated beam to be deflected away from the synchrotron at a smaller production angle. The result is a considerable increase in the flux of K^- mesons in the separated beam.

The complete system for fast ejection of the primary proton beam to the Southwest Experimental Area was installed and put into operation during the past year. It consists of the ferrite kicker, septum magnet, and ejector magnet assemblies. Vacuum chamber sections totaling $\approx$260 ft and some 14 deflecting and focusing magnets were installed for beam transport. All components have operated successfully, and useful experimental beams have been delivered to the neutrino experiment.

A plasma lens for use in conjunction with the neutrino experiment has been designed and fabricated. This device is used to focus the external beam after interaction with a target to increase the neutrino flux and thereby increase the number of events in the spark chamber. A pulsed voltage of 15 kV is supplied to the lens for 20 μsec during every machine pulse; this produces a plasma arc between two electrodes separated by a dielectric tube $\approx$6 ft long. The tube and the electrodes form a vacuum chamber into which an inert gas is bled to serve as a conductor between the electrodes. The lens has been used with some success with the beam but final installation is still in progress.

Fabrication and installation have been completed on the $\approx$400 ft of vacuum system for the high energy separated beam to the 80-in. bubble chamber.

Motor-driven flip targets have continued to perform very reliably; no failures have occurred despite the fact that some of the mechanisms have exceeded 4×10^6 cycles. One remote cycling air lock has been installed in the AGS ring and has been performing satisfactorily. A working prototype of the programmed target change system has been tested and is now being adapted for installation in the machine.

As beam intensities in the AGS increase, induced activities in some machine locations exceed tolerances for even the shortest practical operations. Increasingly these operations must be performed remotely. Some of the special-purpose handling devices in various states of preparation include a programmed target blade changer, a modified air lock which can be remotely replaced, and, in a very early stage of planning, a mechanism for the remote changing of a complete tar-

geting straight section. Investigations into the possibilities of general-purpose remote handling devices are also progressing.

Members of the Division participated in the preparation of a proposal for the construction of a new 500-MeV linear accelerator injector for the AGS and the conversion of the AGS to permit operation at higher intensity.

Additional details of the Division's extensive work at the AGS are given in the section on High Energy Accelerators.

At the Nuclear Engineering Department, in addition to general design and fabrication support for the Reactor Physics Division, major engineering support was provided in the following areas: fuel-handling tools and devices for the UO_2-ThO_2 lattice experiment, a miniature lattice assembly for UO_2 fuel, the Mark II Source Reactor, and a foil experiment for the thermal column at the MRR.

On the HFBR project, members of the Division have been providing engineering support in the following areas: administration, preliminary and final design, procurement, and inspection. Additional support consisted of the design, construction, and installation of reactor components in the HFBR training facility.

In radiation source development and associated areas the following contributions were made. The development of standardized cobalt sources was continued, and the research irradiator at the University of Florida was installed and put into service. Several conceptual designs for both research and production facilities were made. Engineering services for the High Intensity Radiation Development Laboratory (HIRDL) and the radiation chemistry section were continued.

Support work in the area of liquid-metal heat transfer has involved completion of design of a boiling potassium heat transfer loop, a cross-flow rod bundle for a NaK heat transfer loop, and a new eccentric-annulus test section for a mercury heat transfer loop. A pumped boiling sodium loop has been designed and is being fabricated.

Work has been done on the design of liquid-metal magnetohydrodynamic test devices and on the design and construction of a test device for the rotating fluidized-bed missile propulsion reactor concept.

Investigations are in progress on a high-flux reactor to accommodate large in-pile loop and capsule experiments. The possibility of modifying the BGRR to obtain an increased neutron flux is being studied.

Division personnel have participated in the initial studies for the Chemistry Department's proposed deep-mine solar neutrino experiment.

The effort of Division personnel on the chemonuclear loop increased considerably this year. This facility will be used to study gas-phase chemical reactions using fission fragments as an energy source. The design of the in-pile section has been completed, and all major components of the loop have been ordered or designed. The preliminary design of the auxiliary systems is complete, and detailed design of the out-of-pile piping is under way.

The installation in the BGRR of an air-cooled capsule irradiation facility was completed this year. The facility will be used for testing settled bed reactor fuels in a NaK environment at 1400°F. Tests of the facility were completed and two capsule irradiations were made. Work is continuing on the improvement of present capsule designs and the design and construction of capsules for irradiation at the ETR.

A report has been prepared on a 1000-MW(e) settled bed reactor. This sodium-cooled fast breeder reactor could be considered for central station power generation. Both an axial and a radial core are discussed; the reference design and plant layout given are for the axial core.

Representation was maintained on the Research Components Standards Committee of the American Nuclear Society and the Sodium Steam Generator Subcommittee of the AEC's Sodium Components Development Committee.

Personnel assigned to the Physics Department have been involved in many problems of both high and low energy physics. Preliminary design for the conversion of the 60-in. conventional cyclotron to a sector-focused cyclotron has been completed. A full-scale rf model has been fabricated and is being used to develop the rf drive system. Final design is in process and equipment is being purchased.

A polarization spectrometer for use with the HFBR has passed the preliminary design stage. It will position a crystal in six degrees of freedom to direct a precisely monochromated beam of polarized neutrons through a guide field to a target sample held at temperatures close to 0.1°K. All motions are to be remotely actuated and recorded, and the main arm and the 2:1 reducing mechanism are to be accurate to ±3 seconds of arc. The final design and fabrication will be subcontracted shortly.

Six neutron spectrometers have been assembled and tested, and a method for automatically programming a complex of seven neutron spectrometers has been initiated with the Instrumentation Division which will allow independent experimental studies to be made on each machine while under computer control.

Work is continuing on the second version of the high-current particle lens with the fabrication of a new Mylar form for casting the lithium. The lens can be made of sodium if lithium of the proper purity is not obtained. An apparatus to investigate the transfer properties of molten lithium is being constructed which will simulate the actual lens construction.

A spark-chamber film reader was completed, and the first group of experimental photographs is being processed.

A slow neutron chopper system, described in the 1963 Annual Report, is in the final stages of design and some components are being fabricated. The rotors will consist of aluminum forgings with the neutron passages cadmium-plated for absorption. Cadmium plating has been tested on 5-in.-diam aluminum rotors running at 100,000 rpm for 2 days with no evidence of plating failure. It was originally planned to make the horizontally shafted rotor of a cadmium-magnesium alloy. However, by using the aluminum-forging–cadmium-plating system, an increase in safety factor of 1.5 can be obtained.

A vertically shafted fast neutron chopper is in final design and partial fabrication. The rotor consists of an upper and lower disk with retaining lips around the circumference which hold four 90° sectors of sintered tungsten material in a symmetrical relationship. The edges of the insert material form two horizontal slots through the rotor into which are placed collimating slit packages for the neutron beam. The upper and lower disks are made of maraging steel forgings which have a yield strength at room temperature of 289,000 psi.

Each rotor for use in the choppers will be tested at a speed giving a stress factor of 1.25 over the design safety factor of 1.5. A spin-test facility has been set up and instrumented for observation of rotors at different speeds and testing of chopper rotating components. Another spin-test facility with expendable apparatus is being set up to test rotors at overspeed. If a rotor fails at overspeed, the rotor fragments will be brought to a stop by a lining of sand bags and can then be examined.

A finite difference method has been developed for stress analysis of rotating disks with complex loading and asymmetrical geometry. The method, which has been programmed on the computer, permits a design to be investigated very rapidly.

The design of the fast neutron chopper facility for the HFBR is nearing completion. This design involves a system of shielding blocks with a 20-ton motor-driven door and a track system. When the door is opened the chopper system can be removed from the shield on the tracks. In addition, fabrication has started on the in-pile collimation equipment.

The Central Design Group has been engaged in supporting the work of personnel assigned to the Biology, Chemistry, and Medical Departments and the Meteorology Group, as well as augmenting the efforts of personnel assigned to the Physics Department. Work was done on the development of a cell scanner for the Medical Department which traverses a distance of 10 μ with a perpendicular jump of 2 μ. An encapsulating system for protecting tulip bulbs in a satellite from the accelerations of orbital flight and an irradiation source mechanism that electromechanically simulates radiation fallout decay were designed for the Biology Department. Other projects included a machining system for grinding plutonium in a glove box, an intermittent pollen-collecting device, a hodoscope-positioning mechanism, a large aluminum-foil spark chamber, and a flat hydrostatic bearing for moving a 200-ton large-aperture magnet.

Most of the personnel assigned to the Bubble Chamber Group have been involved in the operation of the 20-, 30-, and 80-in. bubble chambers and also in their modification and improvement. Existing film-reading equipment is being adapted to rolls of larger size. Members of this group participated in the preparation of a proposal for a new 14-ft liquid hydrogen bubble chamber facility at BNL.

MACHINE SHOPS

Three general categories of service are provided by the Central Shops Division: on-site fabrication, fabrication by vendors, and inspection and quality control. In addition, management of the Laboratory-wide machine-tool acquisition and replacement program, the machine-tool standards program, and the small-tool standards program are the responsibility of the Division.

Table 8

Contributions to Machine Shops Workload

	% Man-hours		
	Fiscal 1964	Fiscal 1963	Fiscal 1962
Accelerators			
AGS	12.7	11.0	8.4
Cosmotron	9.1	8.3	15.7
Biology	2.1	2.0	2.6
Chemistry	2.1	3.0	3.3
Instrumentation and Health Physics	1.7	1.2	0.9
Medical	1.7	2.4	3.2
Nuclear Engineering	32.8	32.6	28.6
Physics	28.8	32.5	29.7
Reactor	4.8	3.6	4.5
Miscellaneous	2.0	2.1	3.1
Outside contracts	2.2	1.3	

The Division provided 143,872 productive man-hours of work in fiscal 1964, about 4% above the fiscal 1963 level. Table 8 indicates the contributions of the several departments to the Division's workload. The Nuclear Engineering and Physics Departments continue to be the principal contributors, each accounting for $\approx$30% of the entire workload. The Accelerator Department accounted for another 22%. More than 3100 man-hours were applied to work for outside institutions, a substantial increase over the figure for the previous year. Work processed through intralaboratory requisitions accounted for 85.7% of the total, and 14.3% represented work done on a short-order basis. Jobs in the latter category exceeded 20,000 man-hours for the first time. The average backlog was reduced by $>$4000 hr to a level $\approx$22% below that in fiscal 1963. The backlog was still divided $\approx$70 to 30 between the machining section and the sheet metal and welding sections.

The Division's fabrication problems have become increasingly demanding and complex; hence the contracting of fabrication work to vendors is of considerable importance. Although the volume of such work did not increase significantly over that for fiscal 1963, the need for highly qualified and reliable vendors has increased. Work valued at $\approx$\$98,000 was fabricated by 59 different vendors during the year. Individual orders placed varied in amount from \$2.50 to \$8500, with an over-all average of $\approx$\$400. While the orders covered work for 12 departments, the Physics and Nuclear Engineering Departments and the Cosmotron Division accounted for $\approx$85% of the total volume of work contracted to vendors.

A Vendor Survey Committee was established during the year consisting of one member each from the Central Shops Division, the Mechanical Engineering Division, and the Purchasing Division. Vendor firms were surveyed and evaluated, and a list of approved vendors was issued at the end of the year. The high rejection rate ($\approx$30%) of vendor work should be substantially reduced with more experience in the selection of qualified vendors.

The Inspection and Quality Control Section handled 6445 jobs involving 58,322 individual pieces, of which 40,827 were made in the Central Shops and 17,495 by vendors. The high level of in-process inspection maintained in the Division undoubtedly was an important factor in achieving a low rejection rate ($<$4%).

Substantial progress was made during the year in strengthening the machine tool program. A committee was organized to provide over-all advice on the probable future fabrication needs of the Laboratory and their impact on the type, number, and optimum distribution of machine tools on site. About \$200,000 was available for machine tool additions and replacements for the Laboratory during fiscal 1964. Of this amount 76% was applied to replacements and 24% to the acquisition of additional machine tools. About \$145,000 was spent on machine tools for the Division, the balance of \$55,000 being used for the departmental staff shops. Surplus machine tools acquired from the Government in fiscal 1964 had an acquisition value of only \$17,000. This reflects the fact that much of the Government's available inventory of such tools is old, worn out, or obsolete, and the few good tools are requisitioned by Government departments having higher priority.

The Division worked on nearly 2000 jobs during the year and fabricated $>$40,000 individual parts. These jobs ranged from those requiring but a few minutes to one involving $>$4000 man-hours of shop time, and from the simplest type of washer to complex pieces of apparatus requiring extensive experimentation and development in the fabrication process.

A number of jobs were of particular interest. A machine was developed and fabricated for performing a remotely controlled milling operation on the BNL standard cobalt sources to permit recovery of the stainless steel encapsulated cobalt

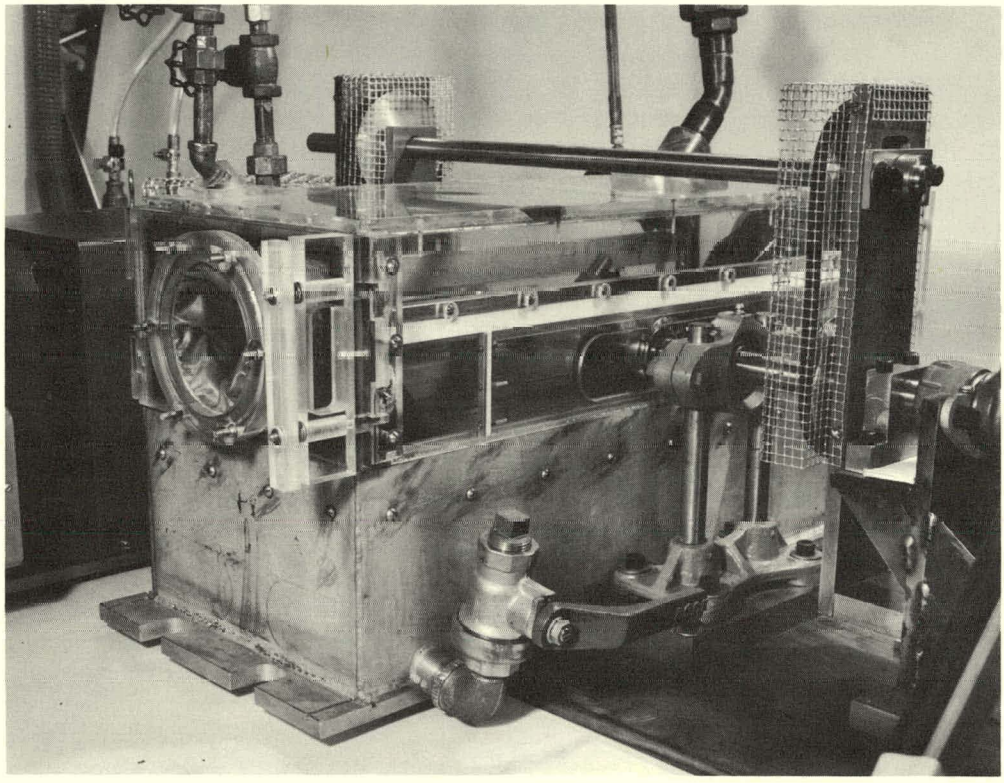


Figure 3. Dry box for semiautomatic welding of thin stainless steel encapsulations of plutonium disks.

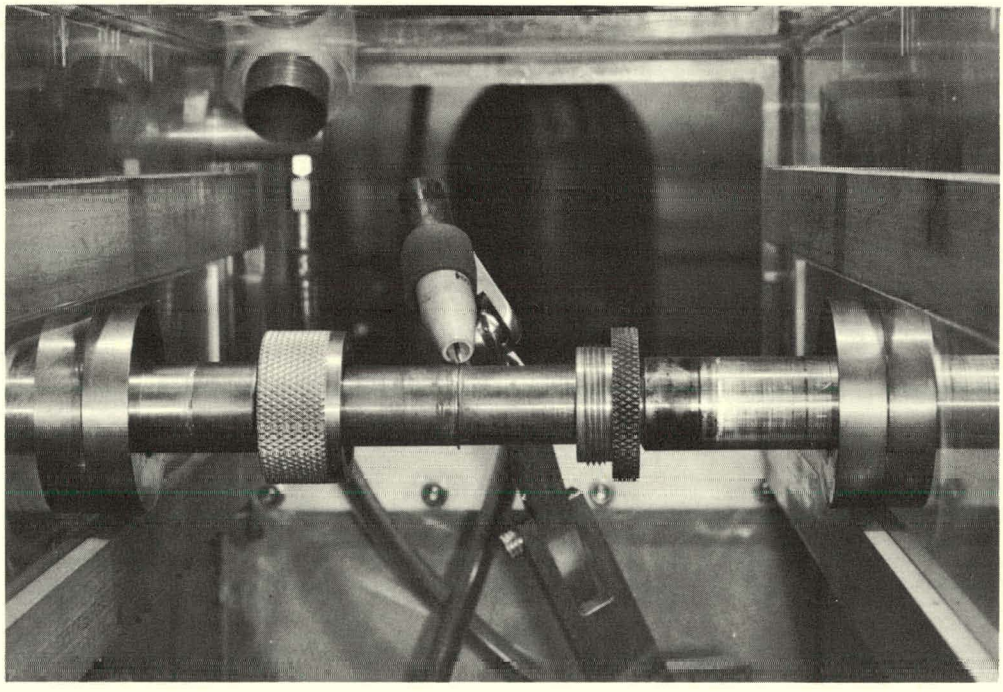


Figure 4. Inside view of dry box, showing positioning and holding fixture and welding tip.

strips after irradiation. This operation had to be accomplished by using a minimum of space and remote-handling devices of limited power. Other requirements were simplicity of tool changes, ease of cleaning, and positive safety.

A special dry box was developed for the semi-automatic encapsulation and welding of disks of plutonium in 0.010-in. stainless steel. Because of the hazards involved in handling plutonium, the dry box was designed to enclose the work completely and provide maximum protection against contamination while at the same time providing simple, accurate, and positive positioning of the parts and torch and removal of gas fumes (see Figures 3 and 4).

Three HFBR fuel element storage cells were fabricated of 304 stainless steel containing 1% boron. Because of the material's costliness these units were fabricated as prototypes in order to obtain realistic cost estimates for outside fabrication of an additional 50 units. A hodoscope positioner, carriage, and a 60-ft length of track were fabricated and subassembled. The track, constructed of 20-in. I-beams, was leveled to 0.010 in., and the positioner provided micrometer adjustment of the vertical and horizontal location of the hodoscope. A 42-in.-diam vacuum tank with a 1-in.-thick wall was fabricated for the slow neutron chopper test facility.

Probably the largest and heaviest piece of equipment, and the one requiring the most machining of any job accomplished by the Division in recent years, was the 3-crystal spectrometer constructed for the Physics Department. It was necessary to roll a 60-in.-diam, 1⅜-in.-wall steel cylinder, perform complex machining operations and heavy welding, and pour lead and boron-paraffin mixtures to complete this 8-ton piece of equipment. The handling alone of such a heavy unit posed serious problems during fabrication. Another job involving large and heavy pieces was the fabrication of a sliding collimator and saddle assembly for the Universal Spectrometer I. This unit was constructed mainly of 2-in.-thick die stock Masonite.

Several jobs involved special tools or procedures, critical dimensions, and close tolerances. Among these were the fabrication of some 2000 zinc combustion boats for the Medical Department by using high-speed steel dies and a punch press, and the fabrication of beryllium targets for the Cosmotron, in which the machining was all done by grinding and special fixtures were needed to obtain the precision required. The fabrication of fuel-handling tongs for the HFBR required high precision to obtain the necessary positive action, and special techniques were developed to eliminate the use of toxic coolants in the process of polishing the internal surfaces of Cb–1 wt % Zr tubing.

Occasionally Division personnel are called upon to perform specialized work on a facility. The extensive repairs required to make the water canal in the HIRDL satisfactory for operation belong in this category. This work involved heliarc welding of stainless steel coves and other pieces requiring difficult welding positions. Meticulous and repeated dye-penetrant inspections were required to locate leaks and check for soundness of repairs, and special provision had to be made for exhausting the fumes from both the welding and the dye-penetrant inspection work.

In addition to the work for Brookhaven groups, the Division also did work during the year for the Massachusetts Institute of Technology, the Weizmann Institute of Science, Columbia University (Nevis Cyclotron Laboratories), the University of Pennsylvania, and Rensselaer Polytechnic Institute.

TECHNICAL INFORMATION

All the Laboratory's technical information activities falling within the scope of the Information Division showed increases over the previous year. In the Research Library, the circulation of books, journals, and reports increased despite the availability of a fast copying service. A saving in book costs was effected with no loss in service by placing orders for domestic publications through a new vendor. Several changes in procedure include the rescheduling of binding shipments at six-week intervals to reduce the time period in which current journals are not on the shelves. The recent addition to the Library staff of a clerk to operate the Xerox copying machine is already resulting in improved and more economical service for users of the library facilities. A preliminary study on the feasibility of maintaining serial records in the Laboratory's Data Processing Division has resulted in a system that is expected to be in operation by the next subscription renewal period. The Reference Section, together with staff members of the Biology and Applied Mathematics Departments, has concluded plans for updating the *Bibliography on the Effects of Ionizing Radiations on Plants, 1896-1955* (BNL 504); information will be stored

in the computer so that indexes can be issued regularly or on demand.

In the Classified Library, more than 1000 reports have been received from other installations. The annual inventory reveals total holdings of 15,700 research and development reports, of which 8000 are secret. No classified formal reports were published by the Laboratory during the past year. With the issuance by Goodyear Atomic Corporation of a compilation entitled *A Supplement to the Indexes of NSA and ACR*, it has been possible to dispense with the subject section of the classified card catalogue. All searching by subject can now be performed by using the indexes in the current issues of *Nuclear Science Abstracts* and *Abstracts of Classified Reports* in conjunction with the Goodyear compilation. Two representatives of the AEC's Declassification Branch were here in September 1963 to review classified correspondence and drawings; this visit resulted in the declassification of ≈300 items, with a consequent reduction in the Laboratory's classified files.

The number of scientific manuscripts originating from Brookhaven-supported research and published as journal articles and Laboratory reports continues to increase. During the year 1044 such documents (including published abstracts of speeches) have been processed by the Information Division, compared with 959 in the previous year, 710 in fiscal 1962, and 708 in fiscal 1961. The Editorial Section, which edits and otherwise prepares formal BNL reports for publication, has also experienced an increased workload.

Exchange agreements continue to be made with foreign research institutions, whereby the Laboratory's reports are exchanged for similar material from many nations. Publications received under such agreements are deposited with the Research Library.

The continuing expansion of the Laboratory's output of technical information was again reflected in the activities of the BNL Patent Office, which is responsible for the review and clearance for patent matters of all scientific manuscripts. The rate of increase in the number of documents requiring such clearance continued the trend first noted in fiscal 1963, with a growth of ≈19% when compared with that year. Although the numbers of preliminary invention reports and records of invention remained within the general range of the past several years, the number of patent applications reached a new high. The continuing growth in patent clearance activity is probably a result of the increased activity in high energy physics associated with the completion of the 80-in. bubble chamber, coupled with the normal growth in the other fields of fundamental research.

Table 9

	Fiscal year		
	1964	1963	1962
Patent clearances	1085	909	768
Preliminary invention reports	43	45	40
Records of invention	27	20	19
Patent applications	14	12	7

Table 9 summarizes the activities of the BNL Patent Office during fiscal 1964 and the two preceding years.

PHOTOGRAPHY AND GRAPHIC ARTS

The general level of activity in the Photography and Graphic Arts Division continued to be high during fiscal 1964. The production figures for the past three years are shown in Table 10 for the Photography Group and in Table 11 for the Graphic Arts Group.

The slight general decrease in the production figures for the Photography Group was more than offset by the large increase in the amount of film processed for the bubble-chamber operations – double the amount processed in fiscal 1963. To meet the demand in this area the operating staff for the 2 film-processing machines was increased from 3 to 5 persons. The rate at which film is exposed at the bubble chambers fluctuates widely, depending on the schedules for AGS operations and for experiments utilizing the bubble chambers. Accordingly, the rate at which film was processed during fiscal 1964 ranged from a low of 58,000 to a high of 880,000 ft/mo, or an average of 378,000 ft/mo for the year. The two film-processing machines have operated well, and it has been possible to step up the output of each machine from 40 to 60 ft/min. A number of components of the machines have been improved as a result of the experience gained from their continued use.

Some additional space for the Photography Group was obtained by converting an old battery room for use as a photomicrography laboratory. This room provided a ground-floor concrete pad on which to mount the microscopes and the equip-

Table 10

	Fiscal year		
	1964	1963	1962
Photographs	12,100	12,937	11,062
Photomicrographs	1,799	2,290	2,768
Lantern slides	13,883	15,423	10,371
Prints	50,990	58,275	52,212
Photostat-Xerox copies	210,680	185,804	46,291
Film processed, ft	4,525,997	2,289,985	1,409,730
Charts and graphs drawn	5,038	6,164	3,982
Motion picture footage	14,794		
Ozalid prints	55,271*	140,981	506,128

*These prints are almost all engineering drawings reproduced on a self-service basis.

ment used for interference microscopy. The greatly improved stability of the instruments, compared with that in the previous second-floor location, has resulted in much more satisfactory operation and consistent quality of the work. This new space includes a small darkroom with a semiautomatic film processor.

The half-hour motion picture mentioned last year, "Of Man and Matter," depicting the AGS and the high energy physics program, has received a Merit Award for "Outstanding Industrial Motion Picture Production in Research and Development Category" from the Princeton Film Review Board. A 15-min film was completed this year on the pilot plant for a process of incorporating fission products in phosphate glass as a medium for the disposal of high-level radioactive wastes.

A design patent was granted for a stand developed by the Illustration Section that greatly increases the portability and flexibility of exhibit displays.

The production figures for the Graphic Arts Group for fiscal 1964 show a small over-all increase over those for 1963 (see Table 11). The 85% increase in the number of Ektalith impressions reflects a shift from mimeograph, photo-offset, and Ozalid processes for the reproduction of preprints, internal reports, and memoranda. The use of the Ozalid machine for many of these items has been all but discontinued. The 1964 figure for Ozalid prints in Table 10 represent the use of this machine on a self-service basis principally for reproduction of engineering drawings and other material requiring large sheets.

Table 11

	Fiscal year		
	1964	1963	1962
Offset impressions	13,304,220	13,709,625	11,207,710
Mimeo impressions	1,430,510	1,721,044	2,283,530
Ektalith impressions	3,715,548	2,008,140	–
Sheets collated and bound	9,035,573	6,773,150	3,363,100
Reports and booklets, copies produced	92,625	75,905	100,725

Three persons were added to the Graphic Arts Group during the year: one was assigned to the Ektalith work, one to composition, and one to the office staff. An Assistant Graphic Arts Supervisor was appointed to be responsible for personnel administration within the Group and to assist the Supervisor in the many operational details. He continued to be responsible for the supervision of the composition work.

A contract was negotiated for the commercial production of Supplement No. 2, *Neutron Cross Sections*, BNL 325, 2nd Ed. This publication, representing $\approx$2 million production units, was needed within 6 to 8 weeks in order to be ready for the Third United Nations International Conference on the Peaceful Uses of Atomic Energy. Because of the short production time the work could not be undertaken by the BNL plant, and it was therefore necessary to purchase the work from a commercial printer.

Some of the larger reports produced by the Graphic Arts Group during the past year are listed below.

	Pages	Total impressions
Brookhaven Symposia in Biology No. 16, Meristems and Differentiation, BNL 805 (C-38)	262	1,179,000
Annual Report, July 1, 1963, BNL 806 (AS-17)	212	508,800
International Conference on Fundamental Aspects of Weak Interactions, BNL 837 (C-39)	474	616,200
Final Safety Analysis Report on the Brookhaven High Flux Beam Research Reactor, BNL 7661 (in 2 volumes)	636	254,400

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

For the second successive year, the number of regular staff members and salaried visitors at Brookhaven increased by ≈10% during the 12 months ending May 31. Comparative year-end statistics for 1963 and 1964 are shown in Table 1. Turnover continued to be significant: 59 scientists and engineers were appointed to the staff, and 27 terminated or were granted leaves of absence, for a net increase of 32 regular staff members.

The number of salaried visitors as of May 31 reached a new high due, in part, to an increase in postdoctoral Research Associate appointments which carry limited terms. During the year, 41 recent graduates began appointments as Research Associates, and 36 terminated or were transferred. Of the latter, 10 were promoted to the regular staff.

Although the number of nonsalaried appointments continued to increase, the number of guests participating at the Laboratory on a full-time basis did not change appreciably. Graduate and undergraduate students held 41 of the additional 93 nonsalaried appointments.

May 31 was used in Table 1 to exclude from the statistics several hundred visitors holding temporary summer appointments. Similarly, the 12-month period ending May 31 was used in Table

Table 1

Scientific Staff and Students on May 31, 1964 and 1963

	Regular staff		Visitors			
			Salaried		Nonsalaried	
	1964	1963	1964	1963	1964	1963
By appointment category						
Staff						
Senior Scientist	66	57	1	1	42	20
Scientist	131	120	10	5	123	121
Associate Scientist	151	130	10	9	120	122
Assistant Scientist	53	62	12	11	84	77
Research Associate	—	—	85	80	62	39
Students						
Junior Research Associate	—	—	4	5	93	75
Research Assistant	—	—	0	0	85	62
Total	401	369	122	111	609*	516**
By academic degree						
Ph.D. or M.D.	276	248	114	103	407	338
Master	52	50	8	5	87	81
Bachelor	68	66	0	3	105	90
No degree	5	5	0	0	10	7

*55 of these appointees were at BNL on a full-time basis as of May 31, 1964.
**57 of these appointees were at BNL on a full-time basis as of May 31, 1963.

Table 2

Classification of Visiting Scientists and Students Participating in BNL Program for One Month or More, June 1, 1963 – May 31, 1964

	Guests and salaried visitors							
	More than 3 months		Less than 3 months		1963 Summer program		Total	
	Salaried	Guest	Salaried	Guest	Salaried	Guest	Individuals	Institutions
University staff	28	35	12	57	75	41	248	106
Thesis students	6	28	1	20	2	4	61	24
Student Research Assistants	1	8	0	18	119	34	180	73
Subtotal	35	71	13	95	196	79	489	142 different
Industry	1	5	0	2	0	4	12	7
Other institutions	20	39	2	21	7	13	102	54
Total	56	115	15	118	203	96	603	203 different

2 to include participants in only one summer program.

Table 2 lists the numbers of visiting scientists (not including salaried Research Associates) and students who worked at Brookhaven for a cumulative period of one month or more during the year. The total of 603 individuals is greater by 10% than the previous all-time high reported last year. In addition to those included in Table 2, 270 scientists and students worked at the Laboratory for less than one month.

Table 3 shows the extent to which consultants' services have been employed during each of the past three years.

Summer Program for 1964

Arrangements have been made for 304 visiting scientists and students to work at Brookhaven during the summer of 1964. Of this number, 164 are students and 140 are staff members from colleges, universities, industrial organizations, and other institutions.

Special groups include 19 Health Physics Fellows and 100 students in the Laboratory's thirteenth annual summer student program.

Labor Relations

New agreements were reached during the year with the Oil, Chemical, and Atomic Workers International Union (Local 8-652) and the Long Island Guards Union.

The OCAW contract which became effective in January 1964 remains basically unchanged. It continues to provide an indefinite contract term and application of the Laboratory's merit wage system, Laboratory policies, and changes in such policies as they apply to nonbargaining-unit wage employees.

The new two-year agreement with the Long Island Guards Union provides for annual rate increases of 2.5% effective in March 1964 and 3.5% in March 1965.

There were no contract negotiations during the year with Directly Affiliated Local Union No. 24426, AFL–CIO. The contract entered into as of December 31, 1962, with this union continues in effect until December 31, 1965.

The Union Relations Committee which was established as a means of communication between DALU and Laboratory management has just completed a successful first year. With a primary

Table 3

Consultants' Services

	Fiscal year		
	1964	1963	1962
Total contracts in effect June 30	92	88	88
No. of consultants used	63	60	59
No. of man-days of service	626	761	577

objective of resolving labor-management problems, the committee of union representatives and members of management have met on more than 20 occasions to freely discuss Union and Laboratory problems as well as other subjects of mutual interest.

Employment

The population of the Laboratory continued to increase during the year (see Figure 1). Early in calendar 1964 BNL passed the 3000 employee mark. For the year, a total of 453 employees joined the Laboratory to fill new employment opportunities, replace retirees, and fill other vacancies. The Laboratory's population, excluding temporary appointees, research collaborators, and guests, has now reached 3065, a net increase of 155 over fiscal 1963 (see Table 4).

This year's new employees were the first to participate in the formal orientation program conducted by the Personnel Department. The program has been successful in acquainting the new employee with the Laboratory's history, organizational structure, personnel policies and practices, and employee services.

A major area of concentration continues to be the seminars conducted for first-line supervisors and other management personnel. A series of supervisory seminars based on the importance of good human relations was held from January through March 1964. More than 175 first-line supervisors participated in the series, which was conducted by a consultant from the Cornell University School of Industrial Relations and members of the personnel staff. In May, other management personnel who are normally more concerned with labor-management decisions were participants in a labor relations seminar directed by the Laboratory's special legal counsel.

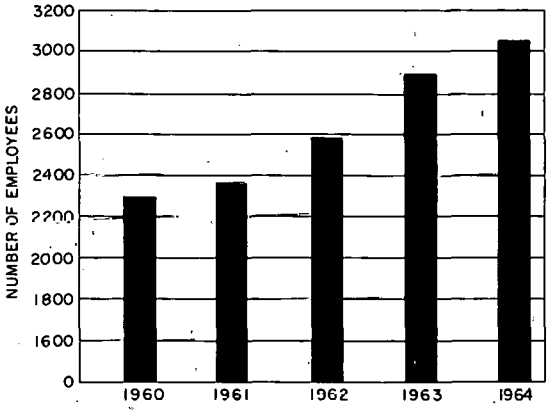


Figure 1. Laboratory growth.

Employee Services

Improvements were made in the Retirement Plan and the Long-Term Disability Insurance program. Very briefly, the improvements are (1) the addition of a tax-deferred option to the retirement annuity plan for monthly salaried exempt employees, and (2) a new provision in the disability insurance plan which offers disabled employees the option of continued participation in the variable annuity option (CREF) of the Laboratory's retirement plan. Previously, the CREF

Table 4

Employment Statistics*

	June 30, 1964	June 30, 1963
Scientific staff	516	477
Professional staff	323	297
Nonscientific staff	2226	2136
Total	3065	2910

Turnover data	Number	1964 Annual rate (%)	Number	1963 Annual rate (%)
Accessions				
Scientific staff	120	24	127	28
Professional staff	69	22	78	28
Nonscientific staff	264	12	403	20
Total	453	15	608	22
Separations				
Scientific staff	81	16	89	19
Professional staff	43	14	37	13
Nonscientific staff	174	8	165	8
Total	298	10	291	11
Net Accessions				
Scientific staff	39	8	38	8
Professional staff	26	8	41	15
Nonscientific staff	90	4	238	12
Total	155	5	317	12

*Figures do not include 87 temporary summer nonstudent employees. Guests and temporary student employees are included in Table 2.

option was not available to an employee while on disability because a separate fixed annuity retirement fund had been established in place of TIAA/CREF for disabled employees.

BNL employees have continued to show increasing interest in self-improvement courses. Under BNL's tuition refund policy, 247 employees have been reimbursed in part for tuition costs of formal courses taken at 13 different universities and colleges.

Fifty-three employees were awarded 10-year service pins, and 16 employees retired during the year.

ARCHITECTURAL PLANNING

The following major building projects, with a total value of slightly less than $29,500,000, were initiated, under construction, or completed during fiscal 1964.

High Flux Beam Research Reactor
Chemistry Building
Instrumentation and Health Physics Building
Controlled Environment Laboratory
Physics and Mathematics addition to the Physics Building
Water treatment plant
Steam plant addition
Low-level radiation counting facility for clinical research

In addition, engineering work will begin this summer on a tandem Van de Graaff accelerator facility whose cost is currently estimated at $12,000,000.

The contracts for architect-engineer and construction work were held by the AEC and administered by its Brookhaven Office, except that for the water treatment plant, which is held by Associated Universities, Inc., and administered at BNL by the Architectural Planning Division. The Division also acted on behalf of BNL in all other work to provide the liaison required from early planning through construction.

Construction is also scheduled to begin in fiscal 1965, contingent on congressional approval, on a Lecture Hall–Cafeteria and extension of site utilities. These projects are currently estimated to cost $2,975,000. Preparation and development of the technical and planning information for these projects are currently under way.

Smaller projects initiated or undertaken during fiscal 1964 amounted to $1,300,000 under the General Plant Projects program. There were more than 150 of these minor additions to, or modifications of, research and supporting staff facilities, many of which presented special engineering problems and required considerable engineering effort. The general plant projects which exceeded $50,000 were as follows: an office building at the AGS; an addition to the north side of the Metallurgy Building; a liquid hydrogen storage facility; an addition to the underground steam distribution system; and an addition to the Central Shops Building. As in past years, the Architectural Planning Division worked closely with the Plant Maintenance Division to coordinate many of these projects.

Early in 1964 the Architectural Planning Division began preparing the facilities section (buildings) of the budget request for fiscal 1966. This involved site locations, preliminary building plans, cost estimates, and descriptive brochures for the projects listed below (total estimated cost, $20,285,000).

Hot Laboratory addition
AGS Target Building addition
AGS Service Building addition
Technical Photography and Graphic Arts Building
Central Shops Building
Supply and Materiel Building
Animal laboratories
Molecular Biology addition
High-Pressure Gamma Radiation Loop Facility
HIRDL addition

During the spring of 1964 the Division assisted the Accelerator Department in delineating the scope of the proposed AGS conversion program and estimating the costs for the buildings, structures, utilities, and site work involved; this also included such layouts and site plans as were required for the final budget proposal report.

PLANT MAINTENANCE

The many responsibilities of the Plant Maintenance Division have made it the most diversified at the Laboratory; its more than 400 employees include engineers, painters, carpenters, electricians, plumbers, janitors, riggers, model makers, telephone and teletype operators, heavy equipment operators, automotive mechanics, mail carriers, drivers, food service workers, housing and travel arrangers, landscapers, and many others.

During the past year the Plant Maintenance Division initiated and substantially completed 195 major maintenance projects and/or facility modi-

fications at a total cost of ≃$800,000. These projects included the incorporation of 4 buildings into 1 to provide additional shop areas for the Utilities Maintenance Group; conversion at the Cosmotron of the machine shop space to 8 laboratories and a utility room; modifications to the gas storage warehouse; preparation of a basement area of the Medical Research Center for use as a fallout shelter; expansion of the Meteorology Group's facilities; refurbishing of 2 waste processing laboratories for the Nuclear Engineering Department; rehabilitation of part of the railroad siding; relocation and rehabilitation of a warehouse in the apartment area; continued progress on air conditioning installations; improvements in lighting, electrical feeders, heating, and plumbing; installation of security fences, fume hoods, access ladders, and roof walks; and interior and exterior painting, waterproofing, and roof repairs.

Telephone, mail, and wire service is part of the responsibility of the Division's Communications Group. In the past 12 months the number of telephone lines has grown from 1376 to 1436, and the number of telephone instruments has increased from 2320 to 2363. The 4% increase in lines and the 2% increase in telephones compare with a 5% increase in total personnel at the Laboratory. New telephone service has been initiated in the Instrumentation and Health Physics Building, Accelerator Development Division, High Flux Beam Research Reactor, AGS Assembly Building, Cosmotron addition, Liquid Hydrogen Storage Facility,

Table 5

Manpower Utilization

Type of work	Fiscal 1964		Fiscal 1963	
	Productive man-years	Percent of total work	Productive man-years	Percent of total work
Maintenance, repairs, and utilities operations	136	36	125	35
Major maintenance programs	10	3	15	4
Facility improvements	6	2	7	2
Research program support	88	23	81	23
Building janitor services	67	18	64	18
Decontamination	6	2	5	1
Hot Laundry operation	7	2	7	2
Conferences and miscellaneous services	7	2	5	1
Telephone and telegraph services	12	3	12	4
Transportation, housing, and mail services	34	9	32	10
Total	373	100	353	100

Table 6

Costs of Supplies, Materials, and Contracts

	Fiscal 1964	Fiscal 1963
Maintenance and utilities materials	$ 313,685	$ 306,826
Major maintenance materials and contracts	451,983	612,605
Facility improvement materials	277,351	351,751
Building janitor supplies	54,211	55,433
Decontamination	329	474
Hot Laundry	21,657	19,571
Fuel oil	305,382	305,336
Electricity	1,694,364	1,310,260
Gasoline	24,490	24,834
Telephone, teletype, and mail	359,221	319,793
Housing and cafeteria	51,838	75,000
Total	$3,554,511	$3,381,883

both the large and small animal quarters, and elsewhere. Plans have been made for telephone service in the dynamatron experimental section of the cyclotron. Provision was made to place underground the overhead telephone lines along Railroad Avenue. A more efficient system of telephone jacks and portable telephones was installed in the AGS Target Building to allow experimental stations to be moved from place to place without incurring additional telephone costs. The Medical Research Center further improved its telephone service through the changeover of 28 manual extensions from its subswitchboard to direct dial lines, which will eventually lead to disconnection of 1 of the 2 operator positions at this switchboard. Toll diversion was accomplished on the foreign exchange trunks to Metropolitan New York along with the application of the group channel rate; this has resulted in a decrease in telephone costs of $800/month. Several "G" wiring plans were disconnected and replaced with the more efficient call-director equipment, and a new data-processing method of automating the telephone equipment records was inaugurated. A standard operating procedure covering the communications function was written, and the groundwork was laid for Laboratory participation in the Federal Telecommunications System, the nationwide Government network of leased long-distance circuits. U.S. mail and intra-Laboratory mail continue to be collected and delivered on a dependable, efficient, regularly scheduled basis between 57 buildings having 88 mail-drop points.

The Laboratory's role as host to scientific seminars, conferences, and meetings is supported by the Division's Staff Services Group, which provides transportation and travel arrangements, housing, and other accommodations required by the participants, who come from all parts of the world. Each year the number of participants in such functions continues to increase markedly.

Continued use was made during the year of the services of consulting engineers in the examination of BNL operating problems. A study of the well clogging problem was conducted by Gibbs and Hill, Inc., of New York to recommend methods for preventing recurrence of incrustating deposits which have clogged the Laboratory's water-supply wells and caused a falloff in pumping capacity.

The utilization of man power and the distribution of costs within the Plant Maintenance Division for fiscal 1963 and 1964 are analyzed in Tables 5 and 6.

SECURITY AND PLANT PROTECTION

The Security and Plant Protection Division continued to perform its assigned functions during fiscal 1964.

Although the scope of the security function at the Laboratory has contracted substantially since Brookhaven's early days, the Laboratory continues nevertheless to maintain an extremely active AEC security clearance program. At the end of fiscal 1964, ≈800 Laboratory employees and affiliates had active "Q" clearances and ≈300 had active "L" clearances. These clearances are required to carry out the classified work at the Laboratory and also to give Brookhaven scientific and technical personnel full access, when necessary, to restricted data, both at BNL and at other laboratories and institutions.

The physical growth of the Laboratory and the expansion of its research program have necessitated ever-increasing emphasis upon the Laboratory's plant protection program. The increase in this aspect of the Division's functions has been met through adaptation of industrial plant protection techniques and practices to the specialized requirements of Brookhaven.

The Fire Group maintained its excellent record in meeting potentially dangerous fire situations at the Laboratory. An active fire-inspection and fire-prevention program is a continuing and important aspect of the Fire Group's activities; close liaison with scientific and technical personnel engaged in research experiments and other activities presenting potential fire hazards is regularly maintained with gratifying results. During the year, fire-fighting equipment has been increased and modernized, and mutual-aid fire-fighting agreements with nearby communities have been continued. Training of the regular fire fighters, as well as the auxiliary and volunteer fire fighters, has been accelerated.

Fortunately, there were no major fires on site during fiscal 1964, and responses to fire alarms decreased, as shown in the tabulation below.

	1964	1963	1962
Responses on site	152	209	165
Responses off site	5	7	7
Investigations	47	70	49
Total	204	286	221

Table 7

Distribution of Personnel

	Staff	Clerical	Fiscal 1964 total	Fiscal 1963 total
Business Office	3	2	5	5
Purchasing Division	17	17	34	31
Supply and Materiel Division	8	75	83	80
Total	28	94	122	116

Table 8

Summary of Business Operations

	Fiscal 1964	Fiscal 1963
Number of procurements	35,628	36,582
Value of procurements	$21,800,000	$24,900,000
Number of receiving actions	41,435	42,697
Number of stores issues	251,584	149,255
Value of inventory turnover	$ 3,418,500	$ 2,935,300

BUSINESS MANAGEMENT

Comparative statistics for Business Office operations during fiscal 1963 and 1964 are given in Tables 7 and 8.

The reductions in the numbers of orders and receiving actions reflect efficiencies gained through bulk procurement under offers of sale, invitation/bid/awards, and charge account agreements, as well as extensive use of electronic data-processing equipment in calculating economic reorder quantities based on physical inventories of selected categories of stock. The higher value of procurements in fiscal 1963 was due to 6 large transactions involving heavy water and data processing equipment totaling ≈$4 million.

Planned progress has been the keynote of Business Office operation during fiscal 1964, especially in the areas of organizational and procedural development and cost improvement. The more significant accomplishments are highlighted below.

Purchasing Division

The Purchasing Division conducted a critical examination of its organization and procedures. The resultant organizational changes and improved methods were documented in a new Purchasing Manual issued in October 1963. Organizational changes included the appointment of a new Purchasing Manager, the realignment of buyers into commodity groupings to afford better work continuity and greater familiarity with product lines, and the assumption of the excess-property acquisition function.

In addition: (1) A Traffic-Rate Guide has been published and distributed to key personnel as an aid in selecting the most economical routing of purchased materials and supplies. (2) Committees have been formed to review vendor facilities and capabilities, and a directory of Approved Machine Shop Vendors has been published which indexes the processes each is capable of handling. (3) A cost reduction program to ensure continued cost awareness has been implemented. (4) Increased emphasis has been placed on procurement negotiations to secure improved prices and/or better discount schedules. (5) Plans for continued progress during fiscal 1965 have been formalized. The active participation of all personnel in the Division's cost reduction program resulted in documented savings estimated to be in excess of $900,000 for fiscal 1964.

Supply and Materiel Division

The Supply and Materiel Division also undertook a self-examination of its organization and procedures. Completion of Phase I of a 2-phase program has resulted in the adoption of many improvements and the publication of a Procedure Manual reflecting operations as of May 1, 1964. Phase II, now under way, entails a more critical review of key areas (flagged in Phase I) requiring closer analysis for long-range improvement.

The Division has continued to expand its use of electronic data processing. The central storage areas are now operating under a "check-out" issue system utilizing prepunched cards. Plans are in progress to operate outlying stockrooms independently under the same system. This new issue system has greatly reduced keypunching time and now provides a greater degree of accuracy in inventory reporting. The new Inventory Management program has been debugged to the extent that machine-calculated reorder quantities are reliable enough to allow consideration of machine preparation of orders and releases to replenish stock.

All inventory items have been converted from manually controlled stock records to edge-punched Smith-Corona-Marchant cards which allow automatic preparation of blanket orders, order/releases, and storage bin tags. In addition, address lists for the internal distribution of catalogues and the external preparation and mailing of excess lists have been prepared for automatic reproduction.

CONFERENCES, PUBLIC INFORMATION, AND EDUCATION

The fifth annual series of George B. Pegram lectures was delivered at the Laboratory on August 26, 28, and 30, 1963, by Dr. J. Robert Oppenheimer, Director of the Institute for Advanced Study. These three lectures, with the title "Niels Bohr and His Times," reviewed the history of physics during the first half of the twentieth century. The lectures, which were held outdoors, were attended by a large number of interested individuals from neighboring communities as well as from the Laboratory staff.

Among the large conferences held at Brookhaven during the fiscal year was the Symposium on Biological Effects of Neutron Irradiations, September 9-11. This was the first meeting sponsored by the International Atomic Energy Agency to be held in the United States; it was attended by $\approx$150 scientists representing 18 foreign countries, 4 international agencies, and the United States. The meeting was opened by Dr. H. Seligman, Deputy Director of the IAEA; the Honorable Glenn T. Seaborg, Chairman of the US AEC, was the banquet speaker. Other conferences were as follows: Evaluated Nuclear Data Files Meeting, May 4-5; National Research Council Solid State Sciences Advisory Panel, May 11-12; AEC Meteorological Activities Conference, May 19-21; and Brookhaven Biology Symposium No. 17, entitled "Subunit Structure of Proteins," June 1-3.

In addition to these conferences, the Laboratory was host organization for the following meetings: Dosimetry Workshop, April 22-24; AEC Advisory Committee for Biology and Medicine, May 7-9; Advisory Committee on Reactor Safeguards Subcommittee Meeting, June 4-5; AEC Division of Isotopes Development Contractors Meeting, June 18-19; and three High Energy Discussion Group meetings, December 12, February 19, and May 7-8. The tenth annual Naval Reserve Nuclear Sciences Seminar was held at Brookhaven, March 1-13, on the topic of Health Physics.

The fourteenth annual Visitors' Day for the general public was attended by 9043 individuals, including students from 110 junior high schools, on October 19. The sixth College Visitors' Day, held on October 25, was attended by 1013 students representing 61 colleges and universities. The tenth annual High School Visitors' Day, held on October 26, was attended by 5682 students from 160 high schools. On February 11, the Laboratory held its eighth annual Science Youth Day in observance of Thomas Alva Edison's birthday. Because of inclement weather only 152 students, representing 28 Suffolk County high schools, were able to attend.

During the year the following foreign groups visited Brookhaven: 6 Japanese chemical engineers, September 26; 13 University of Toronto Engineering Society students, October 31; 11 Russian scientists, headed by Andronik M. Petrosyants, Chairman of the State Committee for Utilization of Atomic Energy, November 19; 18 students from the Institute of Nuclear Science and Engineering, Argonne National Laboratory, January 31; 7 Russian solid state physicists, February 11-12; 11 members of the Euratom Two-Phase Flow Team, April 27; 46 European medical technicians, May 6; 12 Japanese science writers, May 8; and a joint team of 7 USSR and U.S. movie producers, June 10. In addition, 489 professional, governmental, and industrial representatives from foreign countries visited for short periods during the year. Most of these visits were suggested by the AEC.

Other visitors included $\approx$1000 persons representing 28 professional groups and $\approx$150 graduate students representing 10 colleges and universities. Members of 6 National Science Foundation teachers-in-training institutes spent 1 day at the Laboratory, receiving indoctrination in research projects in their particular fields of interest. The Long Island Personnel and Guidance Association held a 1-day meeting at Brookhaven, with 118 teachers in attendance.

In addition to its more routine activities in issuing press releases and servicing requests for technical information from book publishers, students, and the public, the Public Information Office arranged for a press conference on the discovery of the omega-minus particle by a Brookhaven team of physicists. Through the courtesy

and cooperation of the American Institute of Physics, the conference was held on February 21 in the Institute's board room in Manhattan, which ensured optimum attendance. A press kit, including photographs, was prepared for the meeting, which was attended by 40 representatives of domestic and foreign news media. Dr. Maurice Goldhaber presided, giving an introductory review of the research leading up to the experiment in which this important new particle, predicted by theory, was discovered. He was followed by the leading scientists involved in various aspects of the experiment. A question period followed. Undoubtedly, the wide and thorough coverage given in the news to the omega-minus particle was largely due to this meeting.

In the field of education, the activities of the Public Information Office continued to grow, mainly because of the increasing emphasis on the nuclear sciences in school science curricula. This is resulting in a heavy demand for literature and other information and assistance on science projects and term papers. To meet such demands, stocks of more than 150 separate information booklets and brochures are now available. While some of these have originated at Brookhaven, others have been obtained from the AEC's Division of Technical Information and from many other sources. The Laboratory continues to provide speakers for neighboring civic, educational, and semiprofessional audiences and to lend motion pictures from its extensive film library.

Appendix A

PUBLICATIONS, JULY 1, 1963 - JUNE 30, 1964

This list includes official Laboratory publications, abstracts of papers which were or will be presented at scientific meetings, and publications by staff members, consultants, and guests. All these listings result from work done at the Laboratory; they were submitted during the review period.* Abstracts are indicated by (A); letters to the editor, (L); and notes, (N). Acceptance for future publications is designated by (in press).

GENERAL PUBLICATIONS

Annual Report, July 1, 1963. BNL 806 (AS-17).
Progress Reports, Nuclear Engineering Department:
January 1 - April 30, 1963. BNL 799 (S-64).
May 1 - August 31, 1963. BNL 823 (S-65).
September 1 - December 31, 1963. BNL 841 (S-66).
Conference Reports:
Brookhaven Symposia in Biology No. 16. *Meristems and Differentiation.* BNL 805 (C-38).
International Conference on Fundamental Aspects of Weak Interactions, Brookhaven National Laboratory, September 9-11, 1963. BNL 837 (C-39).
Brookhaven Lecture Series:
23. *Neutrino Physics*, L.M. LEDERMAN. BNL 787 (T-300).
26. *Trace Metals: Essential or Detrimental to Life*, G.C. COTZIAS. BNL 828 (T-323).
31. *The Nuclear Reactor Come of Age*, J. CHERNICK. BNL 838 (T-329).
34. *The Biology of Aging*, H.J. CURTIS. BNL 854 (T-340).
High-Temperature Liquid-Metal Technology Review:
Vol. 1, No. 4, August 1963. BNL 825 (PR-4).
Vol. 1, No. 5, October 1963. BNL 836 (PR-5).
Vol. 1, No. 6, December 1963. BNL 844 (PR-6).
Vol. 2, No. 1, February 1964. BNL 855 (PR-7).
Vol. 2, No. 2, April 1964. BNL 866 (PR-8).
Vol. 2, No. 3, June 1964. BNL 875 (PR-9).
Weekly Bulletin **16**, No. 52; **17**, No. 1-52; **18**, 1-5.
Weekly Selected Reading List **16**, No. 15-52; **17**, No. 1-15.

STAFF PUBLICATIONS AND ABSTRACTS

Accelerator Department

ADAIR, R.K. - See LEIPUNER, L.B.
ADAMS, R.R. - See PLOTKIN, M.; SPIRO, J.
ALFF, C., NAUENBERG, U., NUSSBAUM, M., RATAU, J., SCHULTZ, J., STEINBERGER, J., KIRSCH, L., PLANO, R., BERLEY, D., AND PRODELL, A.G. Σ^0-Λ^0 relative parity. (A) *Bull. Am. Phys. Soc.* **8**, 514 (1963).

BARGE, D.A., CHU, W.T., LEIPUNER, L.B., CRITTENDEN, R.R., MARTIN, H.J., KERNAN, W., AYER, F., MARSHALL, L., AND LI, A.C. K^--p interactions at 2.00 BeV/c. (A) *Bull. Am. Phys. Soc.* **9**, 441 (1964).
BARGE, D.A. - See also CHU, W.T.
BARTON, M.Q. Notes on coherent effects in the Cosmotron. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 157-60, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.
BARTON, M.Q., BENNETT, G.W., COTTINGHAM, J.G., ENRIGHT, A.J., GLENN, J.W., HARRIS, J.L., MORGAN, G.H., SMITH, L.W., TRANIS, A., AND WARKENTIEN, R.J. A summary of the Cosmotron experiments on the coherent vertical instability. Informal Report BNL 7674.
BARTON, M.Q., COTTINGHAM, J.G., AND TRANIS, A. Damping of a resistive wall beam instability in the Cosmotron. *Rev. Sci. Instr.* 35, 624-5 (1964).
BENNETT, G.W. - See BARTON, M.Q.
BERLEY, D. A brief description of separated beam #2. Informal Report BNL 7272.
BERLEY, D. Low energy pion and muon fluxes at the AGS. Informal Report BNL 8087.
BERLEY, D. - See also ALFF, C.; BRUGGER, H.
BLEWETT, J.P. Accelerator design studies for production of high center-of-mass energies. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 75-9, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.
BLEWETT, J.P. New design for a proton linear accelerator. Informal Report BNL 7669.
BLEWETT, J.P. Particle accelerators - Synchrotron. Article in *1964 Yearbook of Science and Technology*, McGraw-Hill, New York (in press).
BLEWETT, J.P. - See also VAN STEENBERGEN, A.
BLEWETT, M.H. Experimental beams at the AGS. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 711-17, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.
BLEWETT, M.H. AND DANBY, G.T. Design and performance of bending and quadrupole magnets for the AGS experimental program. *Ibid.*, pp. 767-74.
BRUGGER, H., KIRSCH, L., PLANO, R., BERLEY, D., GELFAND, N., MILLER, D., STEINBERGER, J., AND TAN, T.H. Three-body K^0 decay. (A) *Bull. Am. Phys. Soc.* **8**, 514-15 (1963).

*Also included are those listings from the last annual report [BNL 806 (AS-17)] for which complete reference information was not then available.

CARMEN, R.L. – See SWARTZ, C.E.

CHINOWSKY, W. – See LEIPUNER, L.B.

CHU, W.T., BARGE, D.A., LEIPUNER, L.B., CRITTENDEN, R., MARTIN, H.J., KERNAN, W., AYER, F., MARSHALL, L., AND LI, A.C. Production of Ξ^- and Σ^+ by 2.0-BeV/c K^--p interaction. (A) *Bull. Am. Phys. Soc.* **9**, 441 (1964).

CHU, W.T. – See also BARGE, D.A.; LEIPUNER, L.B.

COTTINGHAM, J.G. Excitation of a linear resonant system from a fast frequency sweeping source. *Proc. IEEE* (in press).

COTTINGHAM, J.G. External beam cross section distribution display. (N) *Rev. Sci. Instr.* **35**, 517-18 (1964).

COTTINGHAM, J.G., GROSSMAN, A.S., AND FELTMAN, A.V. A solid-state motor control for a pulse-loaded 1750-horsepower induction motor. *Elec. Eng.* **82**, 629-32 (1963).

COTTINGHAM, J.G. AND KOVARIK, V.J. Liquified gas level indicator for H_2 and N_2. *Nucl. Instr. Methods* **25**, 244-6 (1964).

COTTINGHAM, J.G. – See also BARTON, M.Q.; FELTMAN, A.V.

COURANT, E.D. Computations in accelerator design. (A) Presented at IBM Scientific Computing Symp. Large-Scale Problems in Physics, Yorktown Heights, N.Y., Dec. 1963.

COURANT, E.D. Particle dynamics in storage rings. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 361-4, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.

COURANT, E.D. Some features of 200-Mc injection into the AGS. Informal Report BNL 7911.

COURANT, E.D. Some remarks regarding high-energy injection into the Brookhaven AGS. Informal Report BNL 7451.

COURANT, E.D. Where is zero? Informal Report BNL 7643.

COURANT, E.D. – See also PLOTKIN, M.

CRITTENDEN, R.R. – See BARGE, D.A.; CHU, W.T.; LEIPUNER, L.B.

DANBY, G.T. AND JACKSON, J.W. Design of small angle beam quadrupoles for the AGS. Informal Report BNL 7438.

DANBY, G.T. AND JACKSON, J.W. Magnetic measurements of AGS experimental beam quadrupoles. Informal Report BNL 7700.

DANBY, G.T., JACKSON, J.W., AND WEISENBLOOM, J. Magnetic measurements of AGS external beam magnets. Informal Report BNL 7862.

DANBY, G.T. – See also BLEWETT, M.H.

ENRIGHT, A.J. – See BARTON, M.Q.

FAUST, J. – See POLK, I.

FELTMAN, A.V. AND COTTINGHAM, J.G. Torque reversing drive for light dc target motor. *Rev. Sci. Instr.* **35**, 814-15 (1964).

FLATAU, C.R. Possible handling methods for radioactivated accelerator components. Informal Report BNL 7706.

FLATAU, C.R. – See also POLK, I.

FORSYTH, E.B. A hydrogen thyratron magnet pulser. *Proc. 8th Symp. Hydrogen Thyratrons and Modulators, Fort Monmouth, N.J., May 1964* (in press).

FORSYTH, E.B. – See also SPIRO, J.

GEFERS, W.F. – See PLOTKIN, M.; SPIRO, J.

GELFAND, N. – See BRUGGER, H.

GLENN, J.W. – See BARTON, M.Q.

GLUCKSTERN, R.L. Coupling of longitudinal and transverse oscillations in linear accelerators. Informal Report BNL 8035.

GLUCKSTERN, R.L. Magnet errors in linear accelerators. Informal Report BNL 7796.

GLUCKSTERN, R.L. RF structure of proton linac beams. Informal Report BNL 7618.

GREEN, G.K. AGS performance and plans. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 110-15, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.

GREEN, G.K. – See also PLOTKIN, M.; SPIRO, J.

HAHN, H. The deflecting mode in circular iris-loaded waveguides. *Rev. Sci. Instr.* **34**, 1094-1100 (1963).

HAHN, H. AND HALAMA, H.J. Perturbation techniques for the deflecting mode. Informal Report BNL 7378.

HALAMA, H.J. – See HAHN, H.; PLOTKIN, M.; SPIRO, J.

HARRIS, J.L. – See BARTON, M.Q.

JACKSON, J.W. – See Danby, G.T.

KIRSCH, L. – See ALFF, C.; BRUGGER, H.

KOVARIK, V.J. – See COTTINGHAM, J.G.

LARSEN, R.C. – See LEIPUNER, L.B.

LASKY, C. Failure of coil #871. Informal Report BNL 7999.

LASLETT, L.J. Coil systems for measurement of field and field-gradient in two-dimensional magnetic fields. Informal Report BNL 7270.

LASLETT, L.J. Some aspects of search coil design. Informal Report BNL 7269.

LEIPUNER, L.B., CHINOWSKY, W., CRITTENDEN, R., ADAIR, R., MUSGRAVE, B., AND SHIVELY, F.T. Anomalous regeneration of K_1^0 mesons from K_2^0 mesons. *Phys. Rev.* **132**, 2285-90 (1963).

LEIPUNER, L.B., CHU, W.T., LARSEN, R.C., AND ADAIR, R. Particles with a charge of $\frac{1}{3}e$. (L) *Phys. Rev. Letters* **12**, 423-5 (1964).

LEIPUNER, L.B. – See also BARGE, D.A.; CHU, W.T.

LEVINE, C.S. – See SWARTZ, C.E.

MASCHKE, A.W. – See SPIRO, J.

MILLER, D. – See BRUGGER, H.

MOORE, W.H. – See Jesseph, J.E. (Medical); LIPPINCOTT, S.W. (Medical).

MORGAN, G.H. – See BARTON, M.Q.

MUSGRAVE, B. – See LEIPUNER, L.B.

NAUENBERG, U. – See ALFF, C.

NUSSBAUM, M. – See ALFF, C.

OLEKSIUK, L.W. – See VAN STEENBERGEN, A.

PARZEN, G. Effects of radial straight sections in a spiral-sector FFAG accelerator. Informal Report BNL 7635.

PARZEN, G. The scalar potential in magnetic field calculations. Informal Report BNL 8080.

PARZEN, G. Space-charge limits and injection and aperture requirements for a 1000-BeV synchrotron. Informal Report BNL 7668.

PLANO, R. – See ALFF, C.; BRUGGER, H.

PLOTKIN, M., ADAMS, R.R., COURANT, E.D., GEFERS, W.F., GREEN, G.K., HALAMA, H.J., RAKA, E.C., AND SPIRO, J. Beam observation and manipulation in the AGS. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 958-64, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.

PLOTKIN, M. – See also SPIRO, J.
POLK, I., FAUST, J., FLATAU, C.R., AND KING, R. Internal target system and induced radioactivity at the AGS. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 745-58, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.
PORTER, C.G. An accurate autoreflection system for theodolites. Informal Report BNL 7268.
RAKA, E.C. – See PLOTKIN, M.
RATAU, J. – See ALFF, C.
READING, O.S. Precision surveying for the 33-GeV synchrotron at Brookhaven National Laboratory. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 116-28, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.
RHEAUME, R.H. Hard tube modulator for the AGS linac rf power amplifier. *Proc. 8th Symp. Hydrogen Thyratrons and Modulators, Fort Monmouth, N.J., May 1964* (in press).
SCHULTZ, J. – See ALFF, C.
SHAYLOR, H.R. The effect of electrical Q and electrical resonance on accelerating cavities. Informal Report BNL 7699.
SHIVELY, F.T. – See LEIPUNER, L.B.
SMITH, L.W. – See BARTON, M.Q.
SPIRO, J., ADAMS, R.R., FORSYTH, E.B., GEFERS, W., GREEN, G.K., HALAMA, H.J., MASCHKE, A.W., AND PLOTKIN, M. Multiple experimental operation at the AGS. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963,* pp.129-36, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.
SPIRO, J. – See also PLOTKIN, M.
STEINBERGER, J. – See ALFF, C; BRUGGER, H.
SWARTZ, C.E., LEVINE, G.S., AND CARMEN, R.L. Nonsaturating ionization chamber for high intensity external proton beam. *Rev. Sci. Instr.* **34**, 1398-9 (1963).
TAN, T.H. – See BRUGGER, H.
THEVENET, B. Energy loss by ionization of relativistic particles in xenon. I. Informal Report BNL 7934.
THEVENET, B. AND ZSEMBERY, J. An empirical pion-nucleon spectroscopy. (L) *Phys. Rev. Letters* **13**, 40-2 (1964).
THEVENET, B. – See also CONNOLLY, P.L. (Physics).
TRANIS, A. – See BARTON, M.Q.
VAN STEENBERGEN, A. Beam current limitations in the AGS with multiple-turn injection related to ion source emittance characteristics. Informal Report BNL 7943.
VAN STEENBERGEN, A. Low-energy injection into an 800-Mc/s linac structure. Informal Report BNL 7910.
VAN STEENBERGEN, A., OLEKSIUK, L.W., AND BLEWETT, J.P. Some characterisitics of the AGS linac beam and related ion source studies. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 489-98, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.
WARKENTIEN, R.J. – See BARTON, M.Q.
WEISENBLOOM, J. – See DANBY, G.T.
ZSEMBERY, J. – See THEVENET, B.

Applied Mathematics Department

AUERBACH, E.H. AND MOORE, S.O. Calculations of inelastic scattering of neutrons by heavy nuclei. *Phys. Rev.* (in press).
AUERBACH, E.H. – See also listing under Nuclear Engineering.
BEARD, W.J., MARR, R.B., RABINOWITZ, G., AND WENESER, B. Current status of the digital pattern recognition program at BNL. In *Proc. Conf. Programming for HPD and Other Flying Spot Devices, Collège de France, Paris, Aug. 1963,* CERN 63-34, pp. 201-8, CERN, Geneva, 1963.
BEARD, W.J. AND WENESER, B. A digital scanning program for single-view bubble-chamber photographs. Informal Report BNL 7323.
CALKIN, J.W. A mathematician looks at bubble- and spark-chamber data processing. In *Proc. Conf. Programming for HPD and Other Flying Spot Devices, Collège de France, Paris, Aug. 1963*, CERN 63-34, pp. 191-200, CERN, Geneva, 1963.
CANNON, J.R. *A priori* estimate for continuation of the solution of the heat equation in the space variable. *Ann. Mat. Pura Appl.* (in press).
CANNON, J.R. A Cauchy problem for the heat equation. *Ann. Mat. Pura Appl.* (in press).
CANNON, J.R. A Dirichlet problem for an equation of mixed type with a discontinuous coefficient. *Ann. Mat. Pura Appl.* **61**, 371-8 (1963).
CANNON, J.R. The numerical solution of the Dirichlet problem for Laplace's equation by linear programming. *J. Soc. Ind. Appl. Math.* **12**, 233-7 (1964).
CANNON, J.R. AND DOUGLAS, J. Three-level alternating-direction iterative methods. *Contrib. Differential Equations* **3**, 189-98 (1964).
CANNON, J.R. AND JONES, B.F. Determination of the diffusivity of an anisotropic medium. *Intern. J. Eng. Sci.* **1**, 453-5 (1963).
CANNON, J.R. AND MILLER, K. Some problems in numerical continuation. Submitted to *Numerische Math.*
CANNON, J.R. – See also FILMER, D.L. (Biology).
FUCHEL, K., GARRISON, J.D., AND ZAVITSAS, L.R. *Eigenvalue Spacing Distributions for Comparison With Experimental Data: A Series of Computer Programs.* BNL 863 (T-346), May 1964.
FUCHEL, K. AND LEGERLOTZ, A. OUTBIN: A 7090/94 binary peripheral computer output system. In *Proc. Share XXII, San Francisco, March 1964*, IBM (in press).
FUCHEL, K. – See also WU, A.C.T.
GARRISON, J.D. – See FUCHEL, K.
HELLER, S., PADWA, L., AND PERLMAN, I. STEAM: A Computer Program To Analyze Spark Chamber Data Obtained by Use of an Automatic Flying Spot Digitizer. BNL 833 (T-237), Dec. 1, 1963.
HELLER, S. – See also WU, A.C.T.
JONES, B.F. – See CANNON, J.R.
LARSEN, A. GRAPE: A computer program for classical many-body problems in radiation damage. I. Informal Report BNL 7979.
LEGERLOTZ, A. – See FUCHEL, K.
MARR, R.B. AND SHIMAMOTO, Y. On a Lee model with a four-point coupling. *Nuovo Cimento* **31**, 599-614 (1964).
MARR, R.B. – See also BEARD, W.J.
MILLER, K. – See CANNON, J.R.
NAKANISHI, N. Asymptotic behavior of the scattering amplitude and normal and abnormal solutions of the Bethe-Salpeter equation. *Phys. Rev.* (in press).
NAKANISHI, N. Fundamental properties of perturbation-theoretical integral representations. III. *J. Math. Phys.* (in press).

NAKANISHI, N. High energy asymptotic expansion of Green's function for forward scattering. (L) Submitted to *Phys. Letters.*

NAKANISHI, N. Invariant solutions of the exact Bethe-Salpeter equation in general-mass case. *J. Math. Phys.* **4**, 1229-35 (1963).

NAKANISHI, N. Perturbation-theoretical integral representation and the high-energy behavior of the scattering amplitude. *Phys. Rev.* **133**, B214-19 (1964).

NAKANISHI, N. Perturbation-theoretical integral representation and the high-energy behavior of the scattering amplitude. II. *Phys. Rev.* **133**, B1224-31 (1964).

NAKANISHI, N. Remarks on the double dispersion approach to the Bethe-Salpeter equation. *J. Math. Phys.* **4**, 1235-40 (1963).

PADWA, L. – See HELLER, S.

PERLMAN, I. – See HELLER, S.

RABINOWITZ, G. Current status of the digital pattern recognition program at BNL. In *Proc. Conf. Programming for HPD and Other Flying Spot Devices, Collège de France, Paris, Aug. 1963*, CERN 63-34, pp. 243-54, CERN, Geneva, 1963.

RABINOWITZ, G. – See also BEARD, W.J.

SHIMAMOTO, Y. – See, MARR, R.B.

SKIBINSKY, M. Maximum likelihood prediction for a two-point bio-assay with prior information. Submitted to *Ann. Math. Statistics.*

WENESER, B. Lorentz invariant momentum space 7090 program LIMS. Informal Report BNL 7308.

WENESER, B. – See also BEARD, W.J.

WU, A.C.T., WU, T.T., AND FUCHEL, K. Intermediate bosons: Pair production cross section by protons. (L) *Phys. Rev. Letters* **11**, 390-4 (1963).

WU, A.C.T., YANG, C., FUCHEL, K., AND HELLER, S. Intermediate bosons: Production cross section from neutrinos. (L) *Phys. Rev. Letters* **12**, 57-61 (1964).

WU, T.T. – See WU, A.C.T.

YANG, C. – See WU, A.C.T.

ZAVITSAS, L.R. – See FUCHEL, K.

Biology Department

ALONZO, N. – See YONDA, A. (Instr. & Health Physics).

AMANO, E. Experiments with ethylmethane sulphonate (EMS) and radiation. *Maize Genetics Cooperative News Letter* **No. 38**, 27-31 (April 15, 1964).

BAKER, D.G., CARSTEN, A.L., AND SAFFORD, C. A method of characterizing protein changes in serum after x-irradiation. *Radiation Res.* **20**, 431-2 (1963).

BARNES, B.G. The fine structure of the mouse adenohypophysis in various physiological states. *Colloq. Intern. Centre Natl. Rech. Sci. Paris* **128**, 91-109 (1963).

BECHERER, F.R. – See WOODWELL, G.M.

BERECH, J. AND CURTIS, H.J. The role of age and x-irradiation on kidney function in the mouse. *Radiation Res.* **22**, 95-105 (1964).

BERGERON, J.A. Studies of the localization, physicochemical properties and action of phyocyanin in *Anacystis nidulans. Proc. Symp. Photosynthetic Mechanisms of Green Plants, Warrenton, Va., Oct. 1963, Natl. Acad. Sci.–Natl. Res. Council Publ.* **1145**, 527-36 (1963).

BISHOP, J.S., STEELE, R., ALTSZULER, N., DUNN, A., BJERKNES, C., AND DEBODO, R.C. Effects of insulin on liver glycogen synthesis and breakdown in the dog. Submitted to *Am. J. Physiol.*

BISHOP, J.S., STEELE, R., DUNN, A., ALTSZULER, N., BJERKNES, C., RATHGEB, I., AND DEBODO, R.C. Hepatic effects of insulin: Inhibition of new glucose release and stimulation of direct uptake of blood glucose for glycogen synthesis. (A) *6th Intern. Congr. Biochemistry, New York, July 1964, Abstracts of Papers*, 714 (1964).

BISHOP, J.S. – See also STEELE, R.

BJERKNES, C. – See BISHOP, J.S.

BLACKMAN, D. – See LUKTON, A.

BOURDEAU, P.F. AND WOODWELL, G.M. Field measurements of carbon dioxide exchange by *Pinus rigida* trees exposed to chronic gamma irradiation. *Ecology* **45**, 403-6 (1964).

BRESCIANI, F. A comparison of the cell generative cycle in normal, hyperplastic and neoplastic mammary gland of the C3H mouse. *Proc. 18th Ann. Symp. Fundamental Cancer Research, Houston, March 1964* (in press).

BRESCIANI, F. Duration and rate of DNA synthesis in the mammary gland of the C3H mouse as studied by incorporation of H^3-thymidine. (A) *6th Intern. Congr. Biochemistry, New York, July 1964, Abstracts of Papers*, 45 (1964).

BRESCIANI, F. Effect of ovarian hormones on duration of DNA synthesis in cells of the C3H mouse mammary gland. Submitted to *Exptl. Cell Res.*

BRESCIANI, F. X-radiations and membrane metabolism connected to active Na-transport. (A) *Radiation Res.* **22**, 170 (1964).

BRESCIANI, F., AURICCHIO, F., AND FIORE, C. A biochemical study of the x-radiation-induced inhibition of active sodium transport (Na pump) in human erythrocytes. *Radiation Res.* **22**, 463-77 (1964).

BRESCIANI, F., AURICCHIO, F., AND FIORE, C. Effect of x-rays on movements of sodium in human erythrocytes. *Radiation Res.* **21**, 394-412 (1964).

BRIGGS, R.W. AND SMITH, H.H. Effects of x-irradiation on intracistron recombination at the *WX/wx* locus. *Maize Genetics Cooperative News Letter* **No. 38**, 25-7 (April 15, 1964).

BROWN, J.A.M., MIKSCHE, J.P., AND SMITH, H.H. An analysis of H^3-thymidine distribution throughout the vegetative meristem of *Arabidopsis thaliana* (L.) Heynh. *Radiation Botany* **4**, 107-13 (1964).

BROWN, J.A.M. AND SMITH, H.H. Incorporation and effects of thymidine analogues in gametophytic tissue of *Arabidopsis thaliana. Mutation Res.* **1**, 45-54 (1964).

BROWN, J.A.M. – See also MIKSCHE, J.P.

BUTERA, R. – See NIMS, L.F.

CARSTEN, A.L. AND INNES, J.R.M. The effects of partial-body irradiation on delayed responses. *Ann. N.Y. Acad. Sci.* **114**, 316-27 (1964).

CARSTEN, A.L. AND NOONAN, T.R. Hematological effects of partial-body and whole-body x-irradiation in the rat. *Radiation Res.* **22**, 136-43 (1964).

CARSTEN, A.L. AND ZEMAN, W. The design and calibration of an x-ray beam facility for radiobiologic studies on mammalian nervous tissues. Submitted to *Radiation Res.*

CARSTEN, A.L. – See also BAKER, D.G.; CAVENESS, W.F.; ZEMAN, W.

CAVENESS, W.F., ROIZIN, L., INNES, J.R.M., AND CARSTEN, A.L. Delayed effects of x-irradiation on the central

nervous system of the monkey. *Proc. 2nd Intern. Symp. Effects of Radiation on the Nervous System, Los Angeles, Aug. 1963* (in press).

COLLINS, R.L. – See ORDY, J.M.

CONTI, S.F. – See MORITA, S.

CRAIGIE, J.S. – See SCOTT, K.J.

CROWLEY, C. – See CURTIS, H.J.

CURTIS, H.J. Biological mechanisms of aging. (A) Presented at Am. Psychological Assoc. Symp. Psychobiology of Aging, Los Angeles, Sept. 1964.

CURTIS, H.J. *The Biology of Aging, Brookhaven Lecture Series No. 34, March 18, 1964.* BNL 854 (T-340).

CURTIS, H.J. Cellular processes involved in aging. *Federation Proc.* **23**, 662-7 (1964).

CURTIS, H.J. Mechanisms of radiation damage in mammals. (A) Presented at Ecological Soc. Meeting, AIBS, Boulder, Colo., Aug. 1964.

CURTIS, H.J. The microbeam as a tool in radiobiology. *Adv. Biol. Med. Phys.* **9**, 207-24 (1963).

CURTIS, H.J. Somatic mutations and carcinogenesis. *Proc. Am. Cancer Soc. Conf. Epidemiological Approaches to Cancer Etiology, Rye, N.Y., May 1964* (in press).

CURTIS, H.J., TILLEY, J., AND CROWLEY, C. The cellular differences between acute and chronic neutron and gamma-ray irradiation in mice. In *Biological Effects of Neutron and Proton Irradiations (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 2, pp. 143-55, IAEA, Vienna, 1964.

CURTIS, H.J., TILLEY, J., AND CROWLEY, C. The elimination of chromosome aberrations in liver cells by cell division. *Radiation Res.* **22**, 730-4 (1964).

CURTIS, H.J. – See also BERECH, J.; ORDY, J.M.

DALY, J. – See SCOTT, K.J.

DAVIES, D.R. Radiation-induced chromosome aberrations and loss of reproductive integrity in *Tradescantia. Radiation Res.* **20**, 726-40 (1963).

DAVIES, D.R. AND BATEMAN, J.L. A high RBE of 650-keV neutrons and 250-kVp x-rays in somatic mutation induction. (L) *Nature* **200**, 485-6 (1963).

DAVIES, D.R., SPARROW, A.H., WOODLEY, R.G., AND MASCHKE, A. The relative biological efficiency of negative μ-mesons and cobalt-60 γ-rays. (L) *Nature* **200**, 277-8 (1963).

DAVIES, D.R. AND WIMBER, D.E. Studies of radiation-induced changes in cellular proliferation, using a double labeling autoradiographic technique. *Nature* **200**, 229-32 (1963).

DEMEREC, M. Clustering of functionally related genes in *Salmonella typhimurium. Proc. Natl. Acad. Sci. U.S.* **51**, 1057-60 (1964).

DEMEREC, M. Gene structure: Genetic fine structure. Remarks. *Proc. 11th Intern. Congr. Genetics, The Hague, Sept. 1963* (in press).

DEMEREC, M. Organization of genetic material in *Salmonella. Proc. 3rd Erwin Baur Symp., Gatersleben, East Germany, Aug. 1963* (in press).

DEMEREC, M. Problems of present-day genetics. *Proc. 11th Intern. Congr. Genetics, The Hague, Sept. 1963 (in press).*

DEMEREC, M. Selfer mutants of *Salmonella typhimurium. Genetics* **48**, 1519-31 (1963).

DEMEREC, M. AND OHTA, N. Genetic analyses of *Escherichia coli* × *Salmonella typhimurium* hybrids. *Proc. Natl. Acad. Sci. U.S.* **52**, 317-23 (1964).

DEMEREC, M. – See also SANDERSON, K.E.

DONNELLY, G.M. Scotch tape No. 810 for making cell locator slides (a simple locator slide). (N) *Stain Technol.* **39**, 184 (1964).

DONNELLY, G.M. AND JAHN, A.H. Radiosensitivity of the salamander *Desmognathus.* (A) *Genetics* **50**, 244 (1964).

DONNELLY, G.M. AND SPARROW, A.H. Large chromosomes: The somatic and meiotic chromosomes of *Amphiuma.* Submitted to *Chromosoma.*

DORNFEST, B.S., LOBUE, J., HANDLER, E.S., GORDON, A.S., AND QUASTLER, H. Mechanisms of leukocyte production and release. II. Factors influencing leukocyte release from isolated perfused rat legs. *J. Lab. Clin. Med.* **60**, 777-87 (1962).

EISENSTARK, S. AND ROSNER, J.L. Chemically induced reversions in the *cysC* region of *Salmonella typhimurium. Genetics* **49**, 343-55 (1964).

ELIAS, J.M. A desiccant-holding slide box for radioautographic exposure. *Stain Technol.* **39**, 235 (1964).

ENGLBERGER, F.M. – See KOSHLAND, M.E.

EVANS, H.J. AND POND, V. The influence of the centromere on chromosome fragment frequency under chronic irradiation. *Port. Acta Biol.* **8**, 125-46 (1964).

EVANS, W.R. – See SMILLIE, R.M.

FILMER, D.L. AND CANNON, J.R. Analysis of a procedure for the determination of kinetic rate constants. Submitted to *Bull. Math. Biophys.*

FILMER, D.L. AND KOSHLAND, D.E. JR. Molecular weight of the phospho and dephospho forms of phosphoglucomutase. *Biochim. Biophys. Acta* **77**, 334-6 (1963).

FILMER, D.L. AND KOSHLAND, D.E. JR. Role of tyrosine residues in chymotrypsin action. *Biochem. Biophys. Res. Commun.* **17**, 189-95 (1964).

FILMER, D.L. – See also OLSON, J.M.; YONDA, A. (Instr. & Health Physics).

FURUYA, M. AND HILLMAN, W.S. Observations on spectrophotometrically assayable phytochrome in etiolated *Pisum* seedlings. Submitted to *Planta.*

FUSSELL, C.P. – See SMITH, H.H.

GORDON, A.S. – See DORNFEST, B.S.

GRAHAM, J.S.D. – See OLSON, J.M.

HADLEY, E.B. – See WOODWELL, G.M.

HANDLER, E.S. – See DORNFEST, B.S.

HEINER, R.E. The effect of tritiated thymidine and diethyl sulfate on *Vicia faba* roots. (A) *Genetics* **50**, 254 (1964).

HEISE, J.J. – See SYBESMA, C.

HILLMAN, W.S. – See FURUYA, M.; HOPKINS, W.G.

HIRS, C.H.W. The chemistry of peptides and proteins. *Ann. Rev. Biochem.* **33**, 597-632 (1964).

HIRS, C.H.W. AND OLCOTT, H.S. The amino acid composition of the myoglobin of the yellowfin tuna (*Thunnus albacares*). (L) *Biochim. Biophys. Acta* **82**, 178-80 (1964).

HIRS, C.H.W. – See also MURDOCK, A.L.; PLUMMER, T.H.; YONDA, A. (Instr. & Health Physics).

HOPKINS, W.G. AND HILLMAN, W.S. Time-course studies of nonphotochemical transformations of phytochrome in etiolated tissue segments. (A) Presented at Am. Soc. Plant Physiologists Meeting, AIBS, Boulder, Colo., Aug. 1964, and Am. Soc. Plant Physiologists Meeting, Storrs, Conn., May 1964.

HORTON, H.R., KARKHANIS, Y.D., AND KOSHLAND, D.E. JR. An environmentally sensitive colored reagent for

the tryptophanyl and cysteinyl residues in proteins. (A) *Federation Proc.* **23**, 161 (1964).

HORTON, H.R. – See also YANKEELOV, J.A.

INNES, J.R.M. – See CARSTEN, A.L.; CAVENESS, W.F.

JAHN, A.H. – See DONNELLY, G.M.

JOHANSEN, T.S. – See MERGEN, F.

KARKHANIS, Y.D. – See HORTON, H.R.; KOSHLAND, D.E. JR.

KLEIN, J.R. Effect of iron deficiency in the duck on the synthesis of protoporphyrin, heme and globin by erythrocytes *in vitro*. (A) *6th Intern. Congr. Biochemistry, New York, July 1964, Abstracts of Papers*, 438 (1964).

KLEIN, J.R. Protoporphyrin compartments in the duck erythrocyte. Submitted to *Am. J. Physiol.*

KOSHLAND, D.E. JR. The active center in enzyme action. In *Volume Cinquantenaire de la Societé de Chimie Biologique*, pp. 201-11, M. Declume, Lons-le Saunier, France, 1964.

KOSHLAND, D.E. JR. Amino acid residues in relation to specificity mechanisms. (A) Presented at Symp. Molecular Aspects of Immunology, Oholo, Israel, March 1964.

KOSHLAND, D.E. JR. Catalysis in life and in the test tube. In *Horizons in Biochemistry*, pp. 265-83, Academic, New York, 1962.

KOSHLAND, D.E. JR. Conformation changes at the active site during enzyme action. *Federation Proc.* **23**, 719-26 (1964).

KOSHLAND, D.E. JR. Correlation of structure and function in enzyme action. *Science* **142**, 1533-41 (1963).

KOSHLAND, D.E. JR. A new technique for the study of conformational changes in protein molecules. (A) Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.

KOSHLAND, D.E. JR. Phosphoglucomutase structure and mechanisms. (A) *6th Intern. Congr. Biochemistry, New York, July 1964, Abstracts of Papers*, 481-2 (1964).

KOSHLAND, D.E. JR. Relation of enzyme structure to function. (A) Presented at Sci. Colloq. Molecular Structure and Biologic Function, Albert Einstein College of Medicine, New York, April 1964.

KOSHLAND, D.E. JR. The role of flexibility in enzyme action. *Cold Spring Harbor Symp. Quant. Biol.* **28**, 473-82 (1963).

KOSHLAND, D.E. JR., BARANY, M., SPRINGHORN, S.S., FINKELMAN, F., AND THERATIL-ANTHONY, T. Adenosinetriphosphate cleavage during the G-actin to F-actin transformation and the binding of adenosinediphosphate to F-actin. *J. Biol. Chem.* **239**, 1917-19 (1964).

KOSHLAND, D.E. JR., KARKHANIS, Y.D., AND LATHAM, H.G. An environmentally sensitive reagent with selectivity for the tryptophan residue in proteins. (L) *J. Am. Chem. Soc.* **86**, 1448-50 (1964).

KOSHLAND, D.E. JR. AND MOZERSKY, S.M. A method for detecting disulfide interchanges in protein modification studies. *Federation Proc.* **23**, 609-12 (1964).

KOSHLAND, D.E. JR. – See also FILMER, D.L.; HORTON, H.R.; LUKTON, A.; STRUMEYER, D.; YANKEELOV, J.A.

KOSHLAND, M.E. Amino acid composition and the specificity of antibodies. (A) Presented at Symp. Molecular Aspects of Immunology, Oholo, Israel, March 1964.

KOSHLAND, M.E., ENGLBERGER, F.M., AND SHAPANKA, R. Differences in the amino acid composition of a third rabbit antibody. *Science* **143**, 1330-1 (1964).

KUEHNERT, C.C. AND MIKSCHE, J.P. Application of the 22.5-MeV deuteron microbeam to the study of morphogenetic problems within the shoot apex of *Osmunda claytoniana* L. *Am. J. Botany* **51**, 743-7 (1964).

KUEHNERT, C.C. – See also MIKSCHE, J.P.

KUGELMAN, B.H. – See SMITH, H.H.

KUO, J. – See NIMS, L.F.

LAMERTON, L.F., LORD, B.I., AND QUASTLER, H. Studies of cell population kinetics in normal and continuously irradiated animals. *Radioaktive Isotope in Klin. und Forsch.* **5**, 493-501 (1963).

LATHAM, H.G. – See KOSHLAND, D.E. JR.; OLSON, J.M.

LEVINE, R.P. AND SMILLIE, R.M. The photosynthetic electron transport chain of *Chlamydomonas reinhardi*. I. Triphosphopyridine nucleotide photoreduction in wild-type and mutant strains. *J. Biol. Chem.* **238**, 4052-7 (1963).

LEVINE, R.P. – See also SMILLIE, R.M.

LOBUE, J. – See DORNFEST, B.S.

LORD, B.I. – See LAMERTON, L.F.

LUKTON, A., BLACKMAN, D., AND KOSHLAND, D.E. JR. Imidazole catalysis of alkyl ester hydrolysis and its relation to chymotrypsin action. *Biochim. Biophys. Acta* **85**, 510-12 (1964).

LYMAN, H. – See SMILLIE, R.M.

MACPHERSON, S. – See OWEN, M.

MARCIELLO, R. AND ZUBAY, G. Quantitative studies on the rate of reaction of adapter RNA with formaldehyde. *Biochem. Biophys. Res. Commun.* **14**, 272-5 (1964).

MASCHKE, A. – See DAVIES, D.R.; MICKE, A.

MERGEN, F. AND JOHANSEN, T.S. Effect of ionizing radiation on microsporogenesis in *Pinus rigida* Mill. *Radiation Botany* **3**, 321-31 (1963).

MERGEN, F. AND JOHANSEN, T.S. Effect of ionizing radiation on seed germination and seedling growth of *Pinus rigida* Mill. Submitted to *Radiation Botany*.

MICKE, A., SMITH, H.H., WOODLEY, R.G., AND MASCHKE, A. Relative biological efficiency of muons and π^- mesons. *Maize Genetics Cooperative News Letter* **No. 38**, 24-5 (April 15, 1964).

MICKE, A., SMITH, H.H., WOODLEY, R.G., AND MASCHKE, A. Relative genetical efficiency of muons and π^- mesons in *Zea mays* and its modification by postirradiation storage. (A) *Radiation Res.* **22**, 216 (1964).

MICKE, A., SMITH, H.H., WOODLEY, R.G., AND MASCHKE, A. Relative mutational efficiency of muons and π^- mesons in *Zea mays*. (L) *Proc. Natl. Acad. Sci. U.S.* **52**, 219-21 (1964).

MIKSCHE, J.P. Changes in radiosensitivity of roots of *Glycine max* (L) Merril. during post-dormant reactivation. Submitted to *Bull. Torrey Botan. Club.*

MIKSCHE, J.P. Cooperative Radiation Mutations Program of Brookhaven National Laboratory – First decade. (A) Presented at IAEA-FAO Tech. Meeting Use of Induced Mutations in Plant Breeding, Rome, May 1964.

MIKSCHE, J.P. DNA content, H^3-thymidine incorporation and nuclear volume as factors related to changes in radiosensitivity during early stages of germination. (A) *Ibid.*

MIKSCHE, J.P. AND BROWN, J.A.M. Development of vegetative and floral meristems of *Arabidopsis thaliana* (L.) Heynh. Submitted to *Am. J. Botany*.

MIKSCHE, J.P. AND KUEHNERT, C.C. Application of the deuteron microbeam to the study of morphogenetic problems within the shoot apex of some ferns. (A) Presented at 10th Intern. Botanical Congr., Edinburgh, Aug. 1964.

MIKSCHE, J.P. AND KUEHNERT, C.C. Ultrastructure of cells of cultured shoot meristems of *Osmunda claytoniana*. (A) *Am. J. Botany* **51**, 667 (1964).

MIKSCHE, J.P. AND SHAPIRO, S. Use of neutron irradiation in the Brookhaven mutations program. In *Biological Effects of Neutron and Proton Irradiations (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 1, pp. 393-408, IAEA, Vienna, 1964.

MIKSCHE, J.P. – See also BROWN, J.A.M.; KUEHNERT, C.C.

MILLER, M.W. A technique for isolating and culturing gemmae of *Marchantia polymorpha* L. under aseptic conditions. Submitted to *Bryologist*.

MORITA, S., OLSON, J.M., AND CONTI, S.F. Light-induced reactions of cytochromes and carotenoids in *Rhodomicrobium vannielii*. *Arch. Biochem. Biophys.* **104**, 346-53 (1964).

MORITA, S. – See also OLSON, J.M.

MOZERSKY, S.M. – See KOSHLAND, D.E. JR.

MURDOCK, A.L. AND HIRS, C.H.W. Further studies of the reaction of ribonuclease A with FDNB. (A) *Federation Proc.* **23**, 424 (1964).

NIMS, L.F. AND BUTERA, R. Ion distribution patterns, membranes and enzymes. (A) Presented at 16th Meeting Am. Physiol. Soc., Providence, Sept. 1964.

NIMS, L.F. AND KUO, J. Electromotive force of transfer systems containing membranes. *J. Appl. Physiol.* **19**, 162-5 (1964).

NOONAN, T.R. – See CARSTEN, A.L.

OHTA, N. – See DEMEREC, M.

OLCOTT, H.S. – See HIRS, C.H.W.

OLSON, J.M., FILMER, D., RADLOFF, R., ROMANO, C.A., AND SYBESMA, C. The protein–chlorophyll-770 complex from green bacteria. In *Bacterial Photosynthesis (Proc. Symp. Charles F. Kettering Foundation, Yellow Springs, Ohio, March 1963)*, pp. 423-31, H. Gest et al., Editors, Antioch Press, Yellow Springs, 1963.

OLSON, J.M., GRAHAM, J.S.D., AND LATHAM, G. The bacteriochlorophyll-bearing protein from green photosynthetic bacteria. (A) *6th Intern. Congr. Biochemistry, New York, July 1964, Abstracts of Papers*, 784 (1964).

OLSON, J.M. AND MORITA, S. Light-induced absorbancy changes in *Rhodomicrobium vannielii*. In *Bacterial Photosynthesis (Proc. Symp. Charles F. Kettering Foundation, Yellow Springs, Ohio, March 1963)*, pp. 433-40, H. Gest et al., Editors, Antioch Press, Yellow Springs, 1963.

OLSON, J.M. AND SMILLIE, R.M. Light-driven cytochrome reactions in *Anacystis* and *Euglena*. *Proc. Symp. Photosynthetic Mechanisms in Green Plants, Warrenton, Va., Oct. 1963, Natl. Acad. Sci.–Natl. Res. Council Publ.* **1145**, 56-65 (1963).

OLSON, J.M. AND SYBESMA, C. Energy transfer and cytochrome oxidation in green bacteria. In *Bacterial Photosynthesis (Proc. Symp. Charles F. Kettering Foundation, Yellow Springs, Ohio, March 1963)*, pp. 413-22, H. Gest et al., Editors, Antioch Press, Yellow Springs, 1963.

OLSON, J.M. – See also MORITA, S.

ORDY, J.M., SAMORAJSKI, T., ZEMAN, W., COLLINS, R.L., AND CURTIS, H.J. Long-term pathologic and behavioral changes in mice after focal deuteron irradiation of the brain. *Radiation Res.* **20**, 30-42 (1963).

OWEN, M. Cell population kinetics of an osteogenic tissue. I. *J. Cell Biol.* **19**, 19-32 (1963).

OWEN, M. AND MACPHERSON, S. Cell population kinetics of an osteogenic tissue. II. *Ibid.*, 33-44.

PERKUS, M.P. – See SCHAEFFER, G.W.

PLUMMER, T.H. AND HIRS, C.H.W. On the structure of bovine pancreatic ribonuclease B. Isolation of a glycopeptide. *J. Biol. Chem.* **239**, 2530-8 (1964).

PLUMMER, T.H. AND HIRS, C.H.W. Studies on the structure of ribonuclease B. (A) Presented at Am. Chem. Soc. Meeting, Denver, Jan. 1964.

POND, V. – See EVANS, H.J.

POSNER, H.B. AND SPARROW, A.H. Survival of *Chlorella* and *Chlamydomonas* after acute and chronic gamma radiation. *Radiation Botany* (in press).

PRENSKY, W. AND SMITH, H.H. Incorporation of ^{3}H-arginine in chromosomes of *Vicia faba*. *Exptl. Cell Res.* **34**, 525-32 (1964).

PRENSKY, W. AND SMITH, H.H. The mechanism of 5-aminouracil induced synchrony of cell division in *Vicia faba* root meristems. Submitted to *J. Cell Biol.*

PRENSKY, W. – See also WIMBER, D.E.

QUASTLER, H. Effects of irradiation on the intestinal cell population. *Federation Proc.* **22**, 1330-3 (1963).

QUASTLER, H. *The Emergence of Biological Organization* (Edited by P.A. Stewart and T.H. Waterman), Yale University Press, New Haven, 1964.

QUASTLER, H. – See also DORNFEST, B.S.; LAMERTON, L.F.; STEIN, O.L.; SMITH, H.H.

RADLOFF, R. – See OLSON, J.M.

REINHARDT, D.J. – See SCHWINGHAMER, E.A.

ROIZIN, L. – See CAVENESS, W.F.

ROMANO, C.A. – See OLSON, J.M.

ROSNER, J.L. – See EISENSTARK, A.

SAFFORD, C. – See BAKER, D.G.

SAMORAJSKI, T. – See ORDY, J.M.

SANDERSON, K.E. AND DEMEREC, M. Genetic map of *Salmonella typhimurium*. *Microbial Genetics Bull.* **20**, 11 (1964).

SAX, K. The stimulation of plant growth by ionizing radiation. *Radiation Botany* **3**, 179-86 (1963).

SAX, K. AND SCHAIRER, L.A. The effect of chronic gamma irradiation on apical dominance of trees. *Radiation Botany* **3**, 283-5 (1963).

SCHAEFFER, G.W., SMITH, H.H., AND PERKUS, M.P. Growth factor interactions in the tissue culture of tumorous and nontumorous *Nicotiana glauca-langsdorffii*. *Am. J. Botany* **50**, 766-71 (1963).

SCHAIRER, L.A. See SAX, K.; SPARROW, A.H.

SCHWINGHAMER, E.A. AND REINHARDT, D.J. Lysogeny in *Rhizobium leguminosarum* and *R. trifolii*. *Australian J. Biol. Sci.* **16**, 597-605 (1963).

SCOTT, K.J., CRAIGIE, J.S., AND SMILLIE, R.M. Pathways of respiration in plant tumors. *Plant Physiol.* **39**, 323-7 (1964).

SCOTT, K.J., DALY, J., AND SMITH, H.H. Effects of indoleacetic acid and kinetin on activities of enzymes of the hexose monophosphate shunt in tissue cultures of *Nicotiana*. *Plant Physiol.* (in press).

SHAPANKA, R. – See KOSHLAND, M.E.

SHAPIRO, S. – See MIKSCHE, J.P.

SHAVER, D.L. *Id* maize. *Maize Genetics Cooperative News Letter* **No. 38**, 23 (April 15, 1964).

SHAVER, D.L. A mechanical method of classifying large number of seeds for waxy. *Maize Genetics Cooperative News Letter* **No. 38**, 22-3 (April 15, 1964).

SHAVER, D.L. Perennialism in *Zea*. *Genetics* **50**, 393-406 (1964).

SHAVER, D.L. Progress towards perennial *Zea* diploids. *Maize Genetics Cooperative News Letter* **No. 38**, 17-20 (April 15, 1964).

SHAVER, D.L. A simple mechanical method of inducing tetraploidy. *Ibid.*, 20-1.

SHAVER, D.L. A successful colchicine method for *Zea*. *Ibid.*, 21-2.

SKOUGAARD, M. Influence of the route of administration of H^3-thymidine on the determination of cell renewal in gingival epithelium of the marmoset. (A) Presented at Intern. Assoc. Dental Research Meeting, Los Angeles, March 1964.

SMILLIE, R.M. Plant fructose-1,6-diphosphatases. In *Fructose-1,6-Diphosphatase and Its Role in Gluconeogenesis*, pp. 31-42, C.R.W. McGilvery and B.M. Pogell, Editors, Am. Inst. Biol. Sci., Washington, 1964.

SMILLIE, R.M. AND EVANS, W.R. Biochemical basis for the obligate photoautotrophy of green bacteria of the genus *Chlorobium*. In *Bacterial Photosynthesis (Proc. Symp. Charles F. Kettering Foundation, Yellow Springs, Ohio, March 1963)*, pp. 151-9, H. Gest et al., Editors, Antioch Press, Yellow Springs, 1963.

SMILLIE, R.M., EVANS, W.R., AND LYMAN, H. Metabolic events during the formation of a photosynthetic from a nonphotosynthetic cell. In *Brookhaven Symposia in Biology No. 16, Meristems and Differentiation*, pp. 89-107, BNL 805 (C-38), March 1964.

SMILLIE, R.M. AND LEVINE, R.P. The photosynthetic electron transport chain of *Chlamydomonas reinhardi*. II. Components of the triphosphopyridine nucleotide-reductive pathway in wild-type and mutant strains. *J. Biol. Chem.* **238**, 4058-62 (1963).

SMILLIE, R.M. – See also LEVINE, R.P.; OLSON, J.M.; SCOTT, K.J.

SMITH, H.H. Inheritance of alkaloids in introgressive hybrids of *Nicotiana*. Submitted to *Am. Naturalist.*

SMITH, H.H. Neutron irradiations: Biological effects. *Science* **143**, 1466-72 (1964).

SMITH, H.H. Relative biological efficiency of monoenergetic fast neutrons on chromosomes in maize. *Maize Genetics Cooperative News Letter* **No. 38**, 23-4 (April 15, 1964).

SMITH, H.H. Response to selection of quantitative character variation induced by radiation. (A) Presented at IAEA-FAO Tech. Meeting Use of Induced Mutations in Plant Breeding, Rome, May 1964.

SMITH, H.H. Stabilized transgression through alien disome addition. (A) *Genetics* **50**, 287 (1964).

SMITH, H.H., BATEMAN, J.L., QUASTLER, H., AND ROSSI, H.H. RBE of monoenergetic fast neutrons: Cytogenetic effects in maize. In *Biological Effects of Neutron and Proton Irradiations (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 2, pp. 233-48, IAEA, Vienna, 1964.

SMITH, H.H., FUSSELL, C.P., AND KUGELMAN, B.H. Partial synchronization of nuclear divisions in root meristems with 5-aminouracil. *Science* **142**, 595-6 (1963).

SMITH, H.H. AND KUGELMAN, B.H. Autoradiographic evidence for incorporation of 2-amino-purine into DNA and RNA of plant cells. Submitted to *Cytologia.*

SMITH, H.H. AND ROSSI, H.H. Comparative rates of chromosome breakage by x-rays and monoenergetic fast neutrons in *Zea mays*. (A) *Radiation Res.* **22**, 236 (1964).

SMITH, H.H. – See also BRIGGS, R.W.; MICKE, A.; PRENSKY, W.; SCHAEFFER, G.W.; SCOTT, K.J.

SPARROW, A.H. Panel on biophysical considerations in neutron experimentation. In *Biological Effects of Neutron and Proton Irradiations (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 2, pp. 397-404, IAEA, Vienna, 1964.

SPARROW, A.H. Relationship between chromosome volume and radiation sensitivity in plant cells. *Proc. 18th Ann. Symp. Fundamental Cancer Research, Houston, March 1964* (in press).

SPARROW, A.H. The tolerance of plants to ionizing radiation: Variations, modifications and predictions. In *Thermonuclear War: Some Effects on People and Nature*, T. Stonier, Editor, Blaisdell, New York (in press).

SPARROW, A.H. Variations in the sensitivity of plant taxa to ionizing radiation. (A) Presented at 10th Intern. Botanical Congr. Edinburgh, Aug. 1964.

SPARROW, A.H., SCHAIRER, L.A., AND SPARROW, R.C. A relationship between estimated interphase chromosome volumes and relative radiosensitivities. (A) *Genetics* **48**, 911 (1963).

SPARROW, A.H., SPARROW, R.C., THOMPSON, K.H., AND SCHAIRER, L.A. The use of nuclear and chromosomal variables in determining and predicting radiosensitivities. *Proc. IAEA-FAO Symp. Use of Induced Mutations in Plant Breeding, Rome, May 1964* (in press).

SPARROW, A.H. AND VAN'T HOF, J. Studies on the kinetics and radiosensitivity of meristems. Presented at 12th Ann. Meeting Radiation Res. Soc., Miami, May 1964.

SPARROW, A.H. – See also DAVIES, D.R.; DONNELLY, G.M.; POSNER, H.B.; STEIN, O.L.; VAN'T HOF, J.; WOODWELL, G.M.

SPARROW, R.C. – See SPARROW, A.H.

SPRINGHORN, S.S. – See KOSHLAND, D.E. JR.

STAIRS, G.R. Acute gamma irradiation of *Quercus* seed – Its effect on germination and seedling growth. *Silvae Genet.* **12**, 192-200 (1963).

STAIRS, G.R. Microsporogenesis and embryogenesis in *Quercus*. *Botan. Gaz.* **125**, 115-21 (1964).

STEELE, R. Reflections on pools. *Federation Proc.* **23**, 671-9 (1964).

STEELE, R., ALTSZULER, N., TOBIN, J., RATHGEB, I., AND DEBODO, R.C. Effect of anti-insulin serum on glucose production and uptake in dogs. (A) Presented at 5th Congr. Intern. Diabetes Federation, Toronto, July 1964.

STEELE, R., BISHOP, J.S., DUNN, A., ALTSZULER, N., RATHGEB, I., AND DEBODO, R.C. Inhibition by insulin of hepatic glucose production in the normal dog. Submitted to *Am. J. Physiol.*

STEELE, R., DEBODO, R.C., ALTSZULER, N., DUNN, A., AND BISHOP, J.S. On the hormonal regulation of carbohydrate metabolism: Studies with C^{14}-glucose. *Recent Progr. Hormone Res.* **19**, 445-88 (1963).

STEEELE, R., WINKLER, B., ALTSZULER, N., AND DEBODO, R.C. Effect of growth hormone and fasting on plasma

free fatty acid (FFA) metabolism in dogs. (A) *Federation Proc.* **23**, 513 (1964).

STEELE, R. – See also BISHOP, J.S.

STEIN, O.L. AND QUASTLER, H. The effect of tritiated thymidine on the morphogenesis of lateral roots in *Zea mays*. *Radiation Res.* **21**, 212-22 (1964).

STEIN, O.L. AND QUASTLER, H. The use of tritiated thymidine in the study of tissue activation during germination in *Zea mays* L. *Am. J. Botany* **50**, 1006-11 (1963).

STEIN, O.L. AND SPARROW, A.H. The effects of chronic gamma irradiation on the growth of *Kalanchoë* cv. Brilliant Star. *Radiation Botany* **3**, 207-22 (1963).

STEWART, P.A. The organization of movement in slime mold plasmodia. In *Primitive Motile Systems in Cell Biology (Proc. Symp., Princeton University, April 1963)*, pp. 69-78 Academic, New York, 1964.

STRUMEYER, D., WHITE, W.N., AND KOSHLAND, D.E. JR. Role of serine in chymotrypsin action. Conversion of the active serine to dehydroalanine. *Proc. Natl. Acad. Sci. U.S.* **50**, 931-5 (1963).

SYBENGA, J. Quantitative analysis of radiation-induced sectorial discoloration of the first leaf of *Crotalaria intermedia*. Submitted to *Radiation Botany*.

SYBESMA, C. AND HEISE, J.J. The light-induced electron spin resonance signals observed in the green bacterium *Chloropseudomonas ethylicum*. In *Bacterial Photosynthesis (Proc. Symp. Charles F. Kettering Foundation, Yellow Springs, Ohio, March 1963)*, pp. 351-6, H. Gest et al., Editors, Antioch Press, Yellow Springs, 1963.

SYBESMA, C. – See also OLSON, J.M.

TAKANAMI, M. AND ZUBAY, G. An estimate of the size of the ribosomal site for messenger RNA binding. *Proc. Natl. Acad. Sci. U.S.* **51**, 834-9 (1964).

TAKANAMI, M. – See also ZUBAY, G.

TAKATS, S.T. An attempt to detect utilization of DNA breakdown products from the tapetum for DNA synthesis in the microspores of *Lilium longiflorum*. *Am. J. Botany* **49**, 748-58 (1962).

TAYLOR, A.L. Bacteriophage-induced mutation in *Escherichia coli*. *Proc. Natl. Acad. Sci. U.S.* **50**, 1043-51 (1963).

THOMPSON, K.H. – See SPARROW, A.H.

TILLEY, J. – See CURTIS, H.J.

VAN'T HOF, J. Discrepancies in mitotic cycle time when measured by tritiated thymidine and colchicine. The effect of tritiated thymidine on the G_1 period duration. Submitted to *Exptl. Cell Res.*

VAN'T HOF, J. An increase in the mitotic cycle duration by a pulse label with tritiated thymidine. (A) *Radiation Res.* **22**, 246 (1964).

VAN'T HOF, J. The influence of sucrose concentration on the minimum mitotic cycle duration of root meristem cells *in vitro*. Submitted to *Exptl. Cell Res.*

VAN'T HOF, J. AND SPARROW, A.H. The effect of mitotic cycle duration on chromosome breakage in meristematic cells of *Pisum sativum*. *Proc. Natl. Acad. Sci. U.S.* **50**, 855-60 (1963).

VAN'T HOF, J. AND SPARROW, A.H. Growth inhibition, mitotic cycle time and cell lethality in chronically irradiated root meristems. *Radiation Botany* **3**, 239-47 (1963).

VAN'T HOF, J. AND YING, H.-K. A relationship between the duration of the mitotic cycle, the rate of cell production and the rate of growth of *Pisum* roots at different temperatures. Submitted to *Cytologia*.

VAN'T HOF, J. AND YING, H.-K. Simultaneous labeling of *Pisum* root cells in different segments of the mitotic cycle with colchicine and tritiated thymidine. (A) *J. Cell Biol.* **19**, 71A-72A (1963).

VAN'T HOF, J. AND YING, H.-K. Simultaneous marking of cells in two different segments of the mitotic cycle. *Nature* **202**, 981-3 (1964).

VAN'T HOF, J. – See also SPARROW, A.H.

WAGNER, R.H. The atumnal seed rain in an irradiated forest. Submitted to *Ecology*.

WHITE, W.N. – See STRUMEYER, D.

WIMBER, D.E. AND PRENSKY, W. Autoradiographic studies on the meiotic chromosomes of the male newt *(Triturus viridescens)* with H^3-thymidine. *Genetics* **48**, 1731-8 (1963).

WIMBER, D.E. – See also DAVIES, D.R.

WOLFSBERG, M.F. Cell population kinetics in the epithelium of the forestomach of the mouse. *Exptl. Cell Res.* **35**, 119-31 (1964).

WOODLEY, R.G. – See DAVIES, D.R.; MICKE, A.

WOODWELL, G.M. Effects of ionizing radiation on major ecosystems. (A) Presented at NAS-NRC Study Group on Civil Defense, Woods Hole, Mass., 1963.

WOODWELL, G.M. Effects of ionizing radiation on natural ecosystems. *Proc. 2nd Congr. Scientists on Survival, New York, June 1963* (in press).

WOODWELL, G.M. Radiation, DDT and biology. (A) Presented at 3rd Congr. Scientists on Survival, New York, June 1964.

WOODWELL, G.M. The radiosensitivity of plant communities. (A) Presented at 10th Intern. Botanical Congr., Edinburgh, Aug. 1964.

WOODWELL, G.M., BECHERER, F.R., AND HADLEY, E.B. The productivity of natural communities. I. An automatic data recording system for monitoring metabolism and microclimate in the field. Submitted to *Ecology*.

WOODWELL, G.M. AND SPARROW, A.H. Effects of ionizing radiation on ecological systems. In *Ecological Effects of Nuclear War*, G.M. Woodwell, Editor, Library Division, Biological and Medical Services, Philadelphia (in press).

WOODWELL, G.M. AND SPARROW, A.H. Predicted and observed effects of chronic gamma radiation on a near-climax forest ecosystem. *Radiation Botany* **3**, 231-7 (1963).

WOODWELL, G.M. – See also BOURDEAU, P.F.

YANKEELOV, J.A., HORTON, H.R., AND KOSHLAND, D.E. JR. A chromatographic study of phosphoglucomutase: Separation of phospho- and dephospho-enzyme forms. *Biochemistry* **3**, 349-55 (1964).

YANKEELOV, J.A. AND KOSHLAND, D.E. JR. Evidence for conformation changes induced by substrates of phosphoglucomutase. Submitted to *J. Biol. Chem.*

YING, H.-K. – See VAN'T HOF, J.

ZEMAN, W. Disturbances of nucleic acid metabolism preceding delayed radionecrosis of nervous tissue. *Proc. Natl. Acad. Sci. U.S.* **50**, 626-30 (1963).

ZEMAN, W. AND CARSTEN, A.L. Cytochemistry of delayed radionecrosis of the murine spinal cord. *Proc. 2nd Intern. Symp. Effects of Ionizing Radiation on the Nervous System, Los Angeles, Aug. 1963* (in press).

ZEMAN, W. – See also CARSTEN, A.L.; ORDY, J.M.

ZUBAY, G. The apparent inability of polypeptides constructed from D-amino acids to stimulate antibody formation. (L) *Nature* **200**, 483-4 (1963).

ZUBAY, G. Metabolic regulation in relation to information storage. (A) Presented at Meeting on Mechanisms for Information Handling in the Nervous System, Phoenix, April 1964.

ZUBAY, G. The molecular basis of differentiation. In *Brookhaven Symposia in Biology No. 16, Meristems and Differentiation*, pp. 170-7, BNL 805 (C-38), March 1964.

ZUBAY, G. Nucleohistone structure and function. In *The Nucleohistones (Proc. 1st World Conf. Histone Biology and Chemistry)*, pp. 95-107, James Bonner and Paul Ts'o, Editors, Holden-Day, Inc., San Francisco, 1964.

ZUBAY, G. Physical and chemical properties of particles. In *Recent Progress in Microbiology (Proc. Intern. Congr., Montreal, Aug. 1962)*, Vol. 7, pp. 65-79, University of Toronto Press, 1963.

ZUBAY, G. Regulation of gene action. Submitted to *J. Theoret. Biol.*

ZUBAY, G. Structure of adapter RNA. *Proc. 11th Intern. Congr. Genetics, The Hague, Sept. 1963* (in press).

ZUBAY, G. AND TAKANAMI, M. Observations on the configuration of nucleotides near the 3'-hydroxy end of adapter RNA. *Biochem. Biophys. Res. Commun.* **15**, 207-13 (1964).

ZUBAY, G. – See also MARCIELLO, R.; TAKANAMI, M.

Chemistry Department

ALLEN, A.O. Radiation yields and reactions in dilute inorganic solutions. *Radiation Res. Suppl. 4*, 54-73 (1964).

ALLEN, A.O. AND HUMMEL, A. Determination of the number of separated ion pairs produced in the irradiation of a liquid. *Discussions Faraday Soc.* **36**, 95-101 (1963).

ALLEN, A.O. – See also KATAKIS, D.; RABE, J.G.

ARNOTT, R.J. – See KUNNMANN, W.

BAUR, W.H. On the cation and water positions in faujasite. *Am. Mineralogist* (in press).

BAUR, W.H. On the crystal chemistry of salt hydrates. II. A neutron diffraction study of $MgSO_4 \cdot 4H_2O$. *Acta Cryst.* **17**, 863-9 (1964); III. The determination of the crystal structure of $FeSO_4 \cdot 7H_2O$ (melanterite). *Ibid.* (in press); IV. The refinement of the crystal structure of $MgSO_4 \cdot 7H_2O$ (epsomite). *Ibid.* (in press).

BERGSTROM, I., CHU, Y.Y., AND EMERY, G.T. *High Resolution at Low Energies With an Iron Double-Focusing Beta-Ray Spectrometer.* BNL 850 (T-336), March 1964.

BIELSKI, B.H.J. AND FREED, S. Enzymatic reactions below 0° of α-chymotrypsin in methanol-water solvents. *Biochim. Biophys. Acta* **89**, 314-23 (1964).

BIELSKI, B.H.J. AND FREED, S. Fluorimetric assay of α-chymotrypsin. *Anal. Biochem.* **7**, 192-8 (1964).

BIELSKI, B.H.J. AND TIMMONS, R.B. Electron paramagnetic resonance study of the photolysis of nitromethane, methyl nitrite, and tetranitromethane at 77°K. *J. Phys. Chem.* **68**, 347-52 (1964).

BIELSKI, B.H.J. – See also CZAPSKI, G.; FREED, S.

BIGELEISEN, J. Correlation of kinetic isotope effects with chemical bonding in three reactions. *Pure Appl. Chem.* **8**, 217-23 (1964).

BRILL, R.H. – See WAMPLER, J.M.

BROECKER, W.S. – See FANALE, F.P.

CAMPION, R.J., CONOCCHIOLI, T.J., AND SUTIN, N. The inner-sphere activated complex for the electron exchange of iron(II) and the monochloro complex of iron(III). *J. Am. Chem. Soc.* (in press).

CAMPION, R.J., PURDIE, N., AND SUTIN, N. The kinetics of some related electron-transfer reactions. *Inorg. Chem.* **3**, 1091-4 (1964).

CAMPION, R.J., PURDIE, N., AND SUTIN, N. The rate of the tris-(2,2'-dipyridine)-osmium(II)–octacyanomolybdate(V) electron-transfer reaction. (L). *J. Am. Chem. Soc.* **85**, 3528 (1963).

CARETTO, A.A. – See GROVER, J.R.

CHEN, J.C.Y. Anharmonicity effects in vibrational excitation of molecules by slow electron impact. (L) *Phys. Letters* **8**, 183-4 (1964).

CHEN, J.C.Y. Off-diagonal hypervirial theorems and their applications. *J. Chem. Phys.* **40**, 615-21 (1964).

CHEN, J.C.Y. Theory of subexcitation electron scattering by molecules. I. Formalism and the negative-ion states; II. Excitation and de-excitation of molecular vibration. *J. Chem. Phys.* **40**, 3507-20 (1964).

CHEN, J.C.Y. Unitary operator formalism of the eigenvalue problems. *J. Chem. Phys.* **39**, 3167-70 (1963).

CHEN, J.C.Y. Vibrational excitation of molecules by slow electron impact. In *Atomic Collision Processes (Proc. 3rd Intern. Conf., London, July 1963)*, pp. 428-39, M.R.C. McDowell, Editor, North-Holland, Amsterdam, 1964.

CHEN, K.L. AND MILLER, J.M. Comparison between reactions of alpha particles with scandium-45 and deuterons with titanium-47. *Phys. Rev.* **134**, B1269-80 (1964).

CHESSIN, H., HAMILTON, W.C., AND POST, B. Position and thermal parameters of oxygen atoms in calcite. Submitted to *Acta Cryst.*

CHRISTMAN, D.R., DAWSON, R.F., AND KARLSTROM, K.I.C. A carbon-by-carbon degradation of carbon-14 labeled nicotinic acid. *J. Org. Chem.* 29, 2394-7 (1964).

CHRISTMAN, D.R. – See also SCHWARTZ, I.L. (Medical).

CHU, Y.Y., FRIEDLANDER, G., AND FRIEDMAN, L. Electromagnetic isotope separator as a tool for basic research. (A) Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.

CHU, Y.Y., KISTNER, O.C., LI, A.C., MONARO, S., AND PERLMAN, M.L. $E2/M1$ ratios in the isomeric transitions of Te^{121} and Te^{123}, and the decay of the Te^{121} isomers to Sb^{121}. *Phys. Rev.* **133**, B1361-7 (1964).

CHU, Y.Y. AND PERLMAN, M.L. Empirical screening correction for M-subshell internal conversion coefficients. *Phys. Rev.* **135**, B319-24 (1964).

CHU, Y.Y. – See also BERGSTROM, I.

CHURCH, L.B. – See PORILE, N.T.

CLARK, R.J.H. – See EISENBERG, R.

COBB, J.C. Determination of lead in meteorites by alpha activation analysis. *J. Geophys. Res.* **69**, 1895-1901 (1964).

COBB, J.C. The problem of lead in stone meteorites. (A) Presented at 26th Meeting Meteoritical Soc., Ottawa, Oct. 1963.

COBB, J.C. AND SCHAEFFER, O.A. Exposure ages for some chondritic meteorites. (A) Presented at Am. Geophys. Union Meeting, Washington, April 1964.

COLLINS, K.E. AND HARBOTTLE, G. Annealing of recoil bromine-82 in hexabromoethane. I. Influence of low concentrations of crystal defects; II. Effects of dose-rate and integrated dose on thermal and radiation annealing. Submitted to *Radiochim. Acta.*

CONOCCHIOLI, T.J., NANCOLLAS, G.H., AND SUTIN, N. The oxidation of iron(II) by cobalt(III) in the presence of chloride ions. (L) *J. Am. Chem. Soc.* **86**, 1453 (1964).

CONOCCHIOLI, T.J., NANCOLLAS, G.H., AND SUTIN, N. The reactions of cobalt(III) with chloride. (L) *Proc. Chem. Soc.* **1964**, 113.

CONOCCHIOLI, T.J. – See also CAMPION, R.J.

COPPENS, P. A neutron diffraction study of 2-nitrobenzaldehyde and the C—H - - O interaction. *Acta Cryst.* **17**, 573 (1964).

CORLISS, L.M. Magnetic structures and neutron diffraction. In *Magnetic Materials Digest 1962*, pp. 29-38, M.H. Francombe and A.J. Heeger, Editors, M.W. Lads Publishing Co., Philadelphia, 1963.

CORLISS, L.M. AND HASTINGS, J.M. Magnetic structure studies at Brookhaven National Laboratory. *Proc. Intern. Colloq. Neutron Diffusion and Diffraction, Grenoble, France, Sept. 1963* (in press).

CORLISS, L.M. AND HASTINGS, J.M. A neutron diffraction investigation of the magnetic structure of $TbMn_2$. *J. Appl. Phys.* **35**, 1051-3 (1964).

CORLISS, L.M. – See also HASTINGS, J.M.

CROSS, R.J. – See CUMMING, J.B.

CUMMING, J.B. Absolute cross section for the $C^{12}(p,pn)C^{11}$ reaction at 50 MeV. *Nucl. Phys.* **49**, 417-23 (1963).

CUMMING, J.B. Monitor reactions for high energy proton beams. *Ann. Rev. Nucl. Sci.* **13**, 261-86 (1963).

CUMMING, J.B. Neutron flux measurements at the AGS. Informal Report BNL 8036.

CUMMING, J.B., CROSS, R.J., HUDIS, J., AND POSKANZER, A.M. Study of a fragmentation reaction by thin-target recoil techniques: Production of Na^{24} from bismuth by 2.9-GeV protons. *Phys. Rev.* **134**, B167-74 (1964).

CUMMING, J.B., KATCOFF, S., PORILE, N.T., TANAKA, S., AND WYTTENBACH, A. Differential range study of products formed by 2.9-GeV proton irradiation of silver. *Phys. Rev.* **134**, B1262-9 (1964).

CUMMING, J.B. – See also KATCOFF, S.; MELONI, S.; POSKANZER, A.M.

CZAPSKI, G. AND BIELSKI, B.H.J. The formation and decay of H_2O_3 and HO_2 in electron-irradiated aqueous solutions. *J. Phys. Chem.* **67**, 2180-4 (1963).

DAVIS, R. Solar neutrinos. II. Experimental. (L) *Phys. Rev. Letters* **12**, 303-5 (1964).

DAVIS, R., DOSTROVSKY, I., POSKANZER, A.M., AND REEDER, P.L. Delayed proton and delayed neutron activities produced at the Cosmotron. (A) Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.

DAVIS, R. – See also SCHAEFFER, O.A.

DAWSON, R.F. – See CHRISTMAN, D.R.

DIEBLER, H. AND SUTIN, N. The kinetics of some oxidation-reduction reactions involving manganese(III). *J. Phys. Chem.* **68**, 174-80 (1964).

DIEHN, B., WOLF, A.P., AND ROWLAND, F.S. Ein Reaktions-Radiogaschromatograph zur Analyse hochsiedender stickstoff- und schwefelhaltiger organischer Verbindungen geringer spezifischer ^{14}C- oder ^{11}C-Aktivität. *Z. Anal. Chem.* **204**, 112-17 (1964).

DIFFENBACH, R. – See EHRENSON, S.

DONOVAN, P.F., KANE, J.V., BAKER, C.P., MOLLENAUER, J.F., AND ZUPANCIC, C. Angular and energy correlations in the reaction $O^{16}(\alpha,2\alpha)C^{12}$ (g.s.) at 40-MeV incident alpha-particle energy. *Phys. Rev.* **135**, B61 (1964).

DONOVAN, P.F., KANE, J.V., MOLLENAUER, J.F., AND PARKER, P.D. The excited states of He^4. *Proc. Intern. Conf. Nuclear Physics, Paris, July 1964* (in press).

DONOVAN, P.F., KANE, J.V., MOLLENAUER, J.F., AND PARKER, P.D. Final state interactions following the reaction of ^3He with ^2H at 12.6-MeV c.m. energy. (A) *Bull. Am. Phys. Soc.* **9**, 389 (1964).

DONOVAN, P.F., KANE, J.V., MOLLENAUER, J.F., AND ZUPANCIC, C. Final state interactions in few nucleon systems. *Proc. Intern. Conf. Nuclear Physics, Paris, July 1964* (in press).

DONOVAN, P.F., MOLLENAUER, J.F., AND WARBURTON, E.K. Inelastic scattering of 10.2-MeV protons by N^{14}. *Phys. Rev.* **113**, B113-16 (1964).

DONOVAN, P.F. – See also BECKER, J.A. (Physics); ALBURGER, D.E. (Physics); MOLLENAUER, J.F.

DOSTROVSKY, I., KATCOFF, S., AND STOENNER, R.W. Decay of Y^{85} isomers. *Phys. Rev.* **132**, 2600-6 (1963).

DOSTROVSKY, I., KATCOFF, S., AND STOENNER, R.W. The decay scheme of Rb^{83}. Submitted to *Phys. Rev.*

DOSTROVSKY, I., KATCOFF, S., AND STOENNER, R.W. Half-lives of ^{83}Y and ^{83}Sr. *J. Inorg. Nucl. Chem.* **26**, 209-11 (1964).

DOSTROVSKY, I., KATCOFF, S., AND STOENNER, R.W. The mode of decay of 83-*d* Rd^{83}. (A) Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.

DOSTROVSKY, I. – See also DAVIS, R.

DULZ, G. AND SUTIN, N. The effect of chloride ions on the kinetics of the oxidation of chromium(II) by iron(III). *J. Am. Chem. Soc.* **86**, 829-32 (1964).

DUNSMORE, H.S. AND NANCOLLAS, G.H. Dissociation of the bisulfate ion. (N) *J. Phys. Chem.* **68**, 1579-81 (1964.)

EHRENSON, S. *A priori* refitting of the Taft equation by non-linear least squares methods. (L) *Tetrahedron Letters* **7**, 351-7 (1964).

EHRENSON, S. Hyperconjugation theory of carbonium ion reactions. *J. Am. Chem. Soc.* **86**, 847-54 (1964).

EHRENSON, S. Theoretical interpretations of the Hammett and derivative structure-reactivity relationships. In *Progress in Physical Organic Chemistry*, Interscience, New York (in press).

EHRENSON, S., SELTZER, S., AND DIFFENBACH, R. Rates of the acid catalyzed interconversions among propylene and the propyl alcohols by n.m.r.: Anti-Markownikoff vs. normal propylene protonation. Submitted to *J. Am. Chem. Soc.*

EISENBERG, R., IBERS, J.A., CLARK, R.J.H., AND GRAY, H.B. Molecular and electronic structure of the bis-(maleonitriledithiolato)-nickelate(II) ion. (L) *J. Am. Chem. Soc.* **86**, 113-15 (1964).

FANALE, F.P., SCHAEFFER, O.A., KAUFMAN, A., THURBER, D.L., AND BROECKER, W.S. Comparison between He:U

and Th^{230}:U^{234} ages of fossil shells and corals. (A). Presented at Am. Geophys. Union Meeting, Washington, April 1964.

FERRETTI, A. – See KUNNMANN, W.

FIREMAN, E.L. AND SCHAEFFER, O.A. Rare gas isotope contents in mineral fractions of the Indarch meteorite. (L) Submitted to *J. Geophys. Res.*

FOREMAN, B.M. Excitation functions for the (p,pn) and $(n,2p)$ reactions on Ce^{142}, 0.37 to 2.85 BeV. *Phys. Rev.* **132**, 1768-70 (1963).

FRANZ, E.M. – See NORRIS, E.A.

FREED, S. AND BIELSKI, B.H.J. Fluorimetric assay of α-chymotrypsin. *Anal. Biochem.* **7**, 192-8 (1964).

FREED, S. – See also BIELSKI, B.H.J.

FRIEDLANDER, G. High-energy nuclear reactions. (A) Presented at Am. Chem. Soc. Meeting, Denver, Jan. 1964.

FRIEDLANDER, G. – See also NORRIS, E.A.; CHU, Y.Y.

FRIEDMAN, L. – See CHU, Y.Y.; KLEIN, F.S.; MORAN, T.F.

GENSLER, W.J. AND MCLEOD, G.L. Fate of the carbinol carbon in the conversion of tetrahydrofurfuryl alcohol to dihydropyran. *J. Org. Chem.* **28**, 3194-7 (1963).

GIBSON, W.M., ERGINSOY, C., AND WEGNER, H.E. Directional dependence of energy loss of 3-MeV protons in thin silicon single crystal. (A) Presented at Symp. Atomic Collision Cascades, Harwell, England, July 1964.

GIBSON, W.M. – See also THOMAS, T.D.

GRAY, H.B. – See EISENBERG, R.

GROVER, J.R. AND CARETTO, A.A. Nucleon, two-nucleon reactions above 100 MeV. *Ann. Rev. Nucl. Sci.* (in press).

GROVER, J.R. AND NAGLE, R.J. Competition between neutron and gamma-ray emission following formation of the compound nucleus Po^{210} in the systems $Pb^{206} + \alpha$ and $Bi^{209} + p$. *Phys. Rev.* **134**, B1248-62 (1964).

HAMILTON, W.C. The crystal structure of orthorhombic acetamide. Submitted to *Acta Cryst.*

HAMILTON, W.C. On-line computer control system for eight diffractometers at the Brookhaven National Laboratory High Flux Beam Reactor. (A) Presented at Am. Crystallographic Assoc. Meeting, Bozeman, Mont., July 1964.

HAMILTON, W.C. Significance tests on the crystallographic *R*-factor. Submitted to *Acta Cryst.*

HAMILTON, W.C. AND IBERS, J.A. Structures of $HCrO_2$ and $DCrO_2$. *Acta Cryst.* **16**, 1209-12 (1963).

HAMILTON, W.C. AND IBERS, J.A. X-ray investigation of the crystal structure of xenon tetrafluoride. In *Noble Gas Compounds*, pp. 195-202, H.H. Hyman, Editor, University of Chicago Press, 1963.

HAMILTON, W.C., IBERS, J.A., AND MACKENZIE, D.R. The geometry of the perxenate ion. *Science* **141**, 532-4 (1963).

HAMILTON, W.C. AND LAPLACA, S.J. The molecular structure of the methyl ester of *o*-nitrobenzenesulfenic acid. (L) *J. Am. Chem. Soc.* **86**, 2289-90 (1964).

HAMILTON, W.C., ROLLETT, J.S., AND SPARKS, R.A. On the relative scaling of x-ray photographs. Submitted to *Acta Cryst.*

HAMILTON, W.C. – See also CHESSIN, H.; IBERS, J.A.; LAPLACA, S.J.

HARBOTTLE, G. – See COLLINS, K.E.; REITZNER, B.

HASTINGS, J.M. AND CORLISS, L.M. A neutron diffraction investigation of the magnetic structure of $TbMn_2$. (A) Presented at 9th Conf. Magnetism and Magnetic Materials, Atlantic City, Nov. 1963.

HASTINGS, J.M. – See also CORLISS, L.M.

HEINZINGER, K. AND WESTON, R.E. JR. Isotopic fractionation of hydrogen between water and the aqueous hydrogen ion. *J. Phys. Chem.* **68**, 744-51 (1964).

HEINZINGER, K. AND WESTON, R.E. JR. Isotopic fractionation of hydrogen between water and the aqueous hydroxide ion. *J. Phys. Chem.* **68**, 2179-83 (1964).

HEINZINGER, K. – See also WESTON, R.E. JR.

HEYMANN, D. – See SCHAEFFER, O.A.

HUDIS, J. Radiochemical techniques. In *Experimental Physics*, A.J. Bearden, Editor, Wiley, New York (in press).

HUDIS, J. – See also CUMMING, J.B.

HUMMEL, A. – See ALLEN, A.O.

HUSH, N.S. The function of bridging groups in electron transfer reactions. Submitted to *Inorg. Chem.*

IBERS, J.A. The nature of the hydrogen bond in the bifluoride ion. *Proc. Intern. Colloq. Neutron Diffusion and Diffraction, Grenoble, France, Sept. 1963* (in press).

IBERS, J.A. Potential function for the stretching region in potassium acid fluoride. *J. Chem. Phys.* **41**, 25-8 (1964).

IBERS, J.A. Refinement of Peterson and Levy's neutron diffraction data on KHF_2. *J. Chem. Phys.* **40**, 402-4 (1964).

IBERS, J.A. Some experiences with least-squares refinements involving rigid groups. (A) Presented at Am. Crystallographic Assoc. Meeting, Bozeman, Mont., July 1964.

IBERS, J.A. Stereochemistry of transition metal carbonyl hydrides. (A) Presented at Symp. Structure and Properties of Coordination Compounds, Bratislava, Czechoslovakia, Sept. 1964.

IBERS, J.A. Structural chemical applications of neutron diffraction. (A) Presented at 2nd Applied Spectroscopy Conf., San Diego, Oct. 1963.

IBERS, J.A. Structure of dibenzene chromium. (N) *J. Chem. Phys.* **40**, 3129-30 (1964).

IBERS, J.A. Structures of some substituted transition metal carbonyls. (A) Presented at Am. Chem. Soc. Meeting, Philadelphia, April 1964.

IBERS, J.A. AND HAMILTON, W.C. Anomalous dispersion and structure refinements. (A) Presented at Am. Crystallographic Assoc. Meeting, Bozeman, Mont., July 1964.

IBERS, J.A. AND HAMILTON, W.C. Dispersion corrections and crystal structure refinements. (N) *Acta Cryst.* **17**, 781-2 (1964).

IBERS, J.A., HAMILTON, W.C., AND MACKENZIE, D.R. The crystal structure of sodium perxenate octahydrate. Submitted to *Inorg. Chem.*

IBERS, J.A. AND LAPLACA, S.J. Molecular structure of the synthetic molecular oxygen carrier $O_2IrCl(CO)(P[C_6H_5]_3)_2$. *Science* **145**, 920-1 (1964).

IBERS, J.A. AND LAPLACA, S.J. Structure of a synthetic molecular oxygen carrier. (A) Presented at 8th Intern. Conf. Coordination Chemistry, Vienna, Sept. 1964.

IBERS, J.A. AND SMITH, G.W. Crystal structure of a sodium cobalt molybdate. *Acta Cryst.* **17**, 190-7 (1964).

IBERS, J.A. – See also EISENBERG, R.; HAMILTON, W.C.; LAPLACA, S.J.; MCGAW, B.L.

KARLSTROM, K.I.C. – See CHRISTMAN, D.R.

KATAKIS, D. AND ALLEN, A.O. Mechanism of radiolytic oxidation of ferrous ion. (N). *J. Phys. Chem.* **68**, 657-60 (1964).

KATAKIS, D. AND ALLEN, A.O. Radiolysis of acid aqueous solutions of aquopentaammine- and hexaammine-cobaltic ions. *J. Phys. Chem.* **68**, 1359-62 (1964).

KATAKIS, D. AND ALLEN, A.O. The radiolysis of aqueous perchloric acid solutions. Submitted to *J. Phys. Chem.*

KATCOFF, S., CUMMING, J.B., PORILE, N.T., TANAKA, S., AND WYTTENBACH, A. Differential range study of products formed by 2.9-GeV proton irradiation of silver. (A) *Bull. Am. Phys. Soc.* **9**, 95 (1964).

KATCOFF, S. – See also CUMMING, J.B.; DOSTROVSKY, I.; POSKANZER, A.M.

KAUFMAN, A. – See FANALE, F.P.

KISTNER, A.M. AND TAYLOR, T.I. Magnetic inelastic scattering of neutrons determined from the total cross sections of MnO and $Mn_{0.5}Zn_{0.5}Fe_2O_4$ as a function of temperature. Submitted to *J. Phys. Chem. Solids.*

KLEIN, F.S. AND FRIEDMAN, L. Intramolecular isotope effects in the HD–rare gas ion molecule reactions. *J. Chem. Phys.* **41**, 1789-98 (1964).

KLEIN, F.S., PERSKY, A., AND WESTON, R.E. JR. The deuterium isotope effect in the chlorine exchange between hydrogen chloride and chlorine atoms. A study of models for the tunnel effect. *J. Chem. Phys.* **41**, 1799-1807 (1964).

KUNNMANN, W., FERRETTI, A., ARNOTT, R.J., AND ROGERS, D.B. Single-crystal growth of transition metal oxides from polytungstate fluxes. Submitted to *J. Phys. Chem. Solids.*

LAPLACA, S.J. AND HAMILTON, W.C. The structure of methyl glyoxal bis(guanylhydrazone) dihydrochloride monohydrate, an antileukemia agent. (A) Presented at Am. Crystallographic Assoc. Meeting, Bozeman, Mont., July 1964.

LAPLACA, S.J., HAMILTON, W.C., AND IBERS, J.A. Crystal and molecular structure of manganese pentacarbonyl hydride. Submitted to *Inorg. Chem.*

LAPLACA, S.J. AND IBERS, J.A. Crystal and molecular structure of tris-triphenylphosphine rhodium carbonyl hydride. Submitted to *Acta Cryst.*

LAPLACA, S.J. AND IBERS, J.A. Studies of the metal-hydrogen bond: Structure of $HRh(CO)(P(C_6H_5)_3)_3$. (L) *J. Am. Chem. Soc.* **85**, 3501-2 (1963).

LAPLACA, S.J., IBERS, J.A., AND HAMILTON, W.C. The geometry of manganese pentacarbonyl hydride: An x-ray diffraction study. (L) *J. Am. Chem. Soc.* **86**, 2288-9 (1964).

LAPLACA, S.J., NOONAN, D., AND POST, B. Ytterbium and terbium dodecaborides. *Acta Cryst* **16**, 1182 (1963).

LAPLACA, S.J. AND SHIMAOKA, K. The crystal structure of carbon suboxide (C_3O_2). (A) Presented at Am. Crystallographic Assoc. Meeting, Bozeman, Mont., July 1964.

LAPLACA, S.J. – See also HAMILTON, W.C.; IBERS, J.A.

LECHTMAN, H.N. AND SAYRE, E.V. Nuclear activation autoradiography of oil paints: A preliminary study. *Proc. Intern. Inst. Conservation of Historic and Artistic Works, St. Louis, May 1964* (in press).

LIFSHITZ, C. AND WOLFSBERG, M. Approximations to energy level distributions. (N) *J. Chem. Phys.* **41**, 1879-80 (1964).

MACKENZIE, D.R. – See HAMILTON, W.C.; IBERS, J.A.

MARCUS, R.A. A generalization of the activated complex theory of reaction rates. Submitted to *J. Chem. Phys.*

MARCUS, R.A. A local approximation of potential energy surfaces by surfaces permitting separation of variables. *J. Chem. Phys.* **41**, 610-16 (1964).

MARCUS, R.A. Separation of sets of variables in quantum mechanics. *J. Chem. Phys.* **41**, 603-9 (1964).

MCGAW, B.L. AND IBERS, J.A. The nature of the hydrogen bond in sodium acid fluoride. *J. Chem. Phys.* **39**, 2677-84 (1963).

MCLEOD, G.L. – See GENSLER, W.J.

MEGRUE, G. – See SCHAEFFER, O.A.

MELONI, S. AND CUMMING, J.B. The $Ce^{142}(p,pn)Ce^{141}$ and $Ce^{142}(p,2p)La^{141}$ reactions from 0.4 to 28 GeV. Submitted to *Phys. Rev.*

MILLER, J.M. – See CHEN, K.L.

MOLLENAUER, J.F. Data simulation with an on-line computer as a diagnostic and analytical tool. *IEEE Trans. Nucl. Sci.* **NS-11**, No. 3, 338-43 (1964).

MOLLENAUER, J.F. Display-oriented data simulation and analysis in multiparameter experiments. Presented at EANDC Conf. Automatic Acquisition and Reduction of Nuclear Data, Karlsruhe, West Germany, July 1964.

MOLLENAUER, J.F., DONOVAN, P.F., AND KANE, J.V. Energy and angular correlations in the reactions $^1H(d,2p)n$, $^2H(p,2p)n$ and $^2H(d,dp)n$. (A) *Bull. Am. Phys. Soc.* **9**, 389 (1964).

MOLLENAUER, J.F. – See also DONOVAN, P.F.

MORAN, T.F. AND FRIEDMAN, L. Application of the Platt electrostatic model to diatomic hydride ions. *J. Chem. Phys.* **40**, 860-6 (1964).

MORAN, T.F. AND FRIEDMAN, L. Neon-hydrogen ion molecule reactions. *J. Chem. Phys.* **39**, 2491-500 (1963).

MULLEN, R.T. AND WOLF, A.P. Isotope distribution in allene and methyl acetylene from the photolysis of carbon-$2^{14}C_1$-suboxide in ethylene. (A) Presented at Am. Chem. Soc. Meeting, Denver, Jan. 1964.

NAGLE, R.J. – See GROVER, J.R.

NANCOLLAS, G.H. AND SUTIN, N. The kinetics of formation of the nickel monooxalate complex in solution. *Inorg. Chem.* **3**, 360-4 (1964).

NANCOLLAS, G.H. – See also CONOCCHIOLI, T.J.; DUNSMORE, H.S.

NORRIS, E.A., FRANZ, E.M., AND FRIEDLANDER, G. Decay of Ce^{131}. (A) Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.

OAE, S., REDVANLY, C.S., AND WOLF, A.P. Recoil and radiation labeling in methanol: A novel synthesis of propanol-2,3,-$C_{1/2}{}^{14}$. (A) Presented at Am. Chem. Soc. Meeting, Denver, Jan. 1964.

PERLMAN, M.L. – See CHU, Y.Y.; CRASEMANN, B. (Physics); THOMAS, T.D.

PERSKY, A. – See KLEIN, F.S.

PORILE, N.T. The evaporation of alpha particles in the interaction of high-energy protons with AgBr. *Phys. Rev.* **135**, B371-7 (1964).

PORILE, N.T. Ranges of low-energy gallium atoms in copper and zinc. *Phys. Rev.* **135**, A1115-8 (1964).

PORILE, N.T. AND CHURCH, L.B. Isobaric yield distributions in the interaction of 1.8-GeV protons with Zr^{96}, Mo^{96}, and Ru^{96}. *Phys. Rev.* 133, B310-17 (1964).

PORILE, N.T. AND TANAKA, S. Differential range studies of Na^{24} formed in high-energy spallation reactions. (A) *Bull. Am. Phys. Soc.* 9, 95 (1964).

PORILE, N.T. AND TANAKA, S. Formation of sodium and potassium nuclides in the bombardment of light elements with 29-GeV protons. Submitted to *Phys. Rev.*

PORILE, N.T. AND TANAKA, S. (p,pxn) Reactions of Br^{79} and Br^{81} with 2.9-GeV protons. *Phys. Rev.* 132, 397-400 (1963).

PORILE, N.T. – See also CUMMING, J.B.; KATCOFF, S.

POSKANZER, A.M. AND REMSBERG, L.P. The $C^{12}(\pi^-,\pi^-n)C^{11}$ excitation function. *Phys. Rev.* 134, B779-82 (1964).

POSKANZER, A.M., REMSBERG, L.P., KATCOFF, S., AND CUMMING, J.B. The $C^{12}(p,pn)C^{11}$ cross section at 1.0 GeV. *Phys. Rev.* 133, B1507-8 (1964).

POSKANZER, A.M. – See also CUMMING, J.B.; DAVIS, R.; SCHWARZSCHILD, A. (Physics).

POST, B. – See CHESSIN, H.

PURDIE, N. – See CAMPION, R.J.

RABE, B. – See RABE, J.G.

RABE, J.G., RABE, B., AND ALLEN, A.O. Radiolysis in the adsorbed state. (L) *J. Am. Chem. Soc.* 86, 3887-8 (1964).

RAMAN, S. Crystal structure of $KTeO(OH)_5 \cdot H_2O$. *Inorg. Chem.* 3, 634-8 (1964).

RAMAN, S. The theory and applications of accumulation functions. *Z. Krist.* (in press).

REDVANLY, C.S. – See OAE, S.

REEDER, P.L. – See DAVIS, R.

REITZNER, B. AND HARBOTTLE, G. Hot-atom chemistry and thermal decomposition of sodium azide crystals containing nitrogen-13 recoil atoms. *Radiochim. Acta.* 2, 132-8 (1964).

REMSBERG, L.P. – See POSKANZER, A.M.

ROGERS, D.B. – See KUNNMANN, W.

ROLLETT, J.S. – See HAMILTON, W.C.

ROWLAND, F.S. – See DIEHN, B.

RUBINSON, W. The present experimental and theoretical status of the problem of electron ejection in the alpha decay of Po^{210}. *Proc. Conf. Role of Atomic Electrons in Nuclear Transformations, Warsaw, Sept. 1963* (in press).

RUSH, J.J. AND TAYLOR, T.I. Rotational motions in hexamethylbenzene and ammonium perchlorate by cross-section measurements with slow neutrons. *J. Phys. Chem.* 68, 2534-7 (1964).

SAYRE, E.V. The intentional use of antimony and manganese in ancient glasses. In *Advances in Glass Technology (Proc. Intern. Glass Congr., Washington, July 1962)*, Pt. 2, pp. 263-82, Plenum Press, New York, 1963.

SAYRE, E.V. Methods and applications of activation analysis. *Ann. Rev. Nucl. Sci.* 13, 145-62 (1963).

SAYRE, E.V. The use of low energy radioactive isotopes in the examination of paintings on thin supports. *Proc. Asian Art Conservation Lab. Paper and Textile Supported Art Objects Symp., New York and Columbia Univ., Nov. 1961* (in press).

SAYRE, E.V. AND SMITH, R.W. Some materials of glass manufacturing in antiquity. *Proc. 3rd Symp. Archaeological Chemistry, Atlantic City, 1962* (in press).

SAYRE, E.V. – See also LECHTMAN, H.N.

SCHAEFFER, O.A., DAVIS, R., STOENNER, R.W., AND HEYMANN, D. The temporal and spatial variation in cosmic rays. *Proc. Intern. Conf. Cosmic Rays, Jaipur, India, Dec. 1963* (in press).

SCHAEFFER, O.A., MEGRUE, G., AND THOMPSON, S.O. Experiments to test the presence of cosmogenic nuclides in ocean sediments. Submitted to *Ann. N.Y. Acad. Sci.*

SCHAEFFER, O.A. – See also COBB, J.C.; FANALE, F.P.; FIREMAN, E.L.; THOMPSON, S.O.

SCHULER, R.H. Production of methyl radicals in the recoil chemistry of carbon-11. *J. Phys. Chem.* 68, 1618-20 (1964).

SCHULER, R.H. The radiolysis of benzene by heavy ions. Submitted to *Trans. Faraday Soc.*

SCHWARZ, H.A. Absolute rate constants for some hydrogen atom reactions in aqueous solution. *J. Phys. Chem.* 67, 2827-30 (1963).

SCHWARZ, H.A. Intensity effects, pulsed beam effects, and the current status of diffusion kinetics. *Radiation Res. Suppl. 4*, 89-113 (1964).

SELTZER, S. The mechanism of the Diels-Alder reaction of 2-methylfuran with maleic anhydride. Submitted to *J. Am. Chem. Soc.*

SELTZER, S. Secondary α-deuterium isotope effects and the mechanism of the thermal decomposition of α-phenylethylazomethane. (A) Presented at Am. Chem. Soc. Meeting, Denver, Jan. 1964.

SELTZER, S. – See also EHRENSON, S.; ZAVITSAS, A.A.

SHIMAOKA, K. – See LAPLACA, S.J.

SLAVIN, M. Range and error of densitometers for emission spectroscopy. Submitted to *Appl. Spectry.*

SMITH, G.W. – See IBERS, J.A.

SMITH, R.W. – See SAYRE, E.V.

SPARKS, R.A. – See HAMILTON, W.C.

STERN, M.J., VAN HOOK, W.A., AND WOLFSBERG, M. Isotope effects on internal frequencies in the condensed phase resulting from interactions with the hindered translations and rotations: The vapor pressures of the isotopic ethylenes. *J. Chem. Phys.* 39, 3179-96 (1963).

STERN, M.J. AND WOLFSBERG, M. Theoretical consideration on carbon isotope effects in the decarboxylation of malonic acid. (L) *Ibid.*, 2776-7 (1963).

STERN, M.J. – See also WOLFSBERG, M.

STÖCKLIN, G. AND WOLF, A.P. The chemistry of hot carbon atoms produced by the $^{12}C(n,2n)^{11}C$-, $^{12}C(p,pn)^{11}C$- and the $^{16}O(p,pn\alpha)^{11}C$-reaction. (A) Presented at Gesselschaft Deutscher Chemiker, Heidelberg, Sept. 1963.

STÖCKLIN, G. AND WOLF, A.P. Radiogaschromatography of weak β rays. (A) Presented at Gesselschaft Deutscher Chemiker, Heidelberg, Sept. 1963.

STÖCKLIN, G. – See also WOLF, A.P.

STOENNER, R.W. – See DOSTROVSKY, I.; SCHAEFFER, O.A.

SUTIN, N. The mechanisms of some electron transfer reactions in solution. Presented at Intern. Symp. Oxidase and Related Oxidation-Reduction Systems, Amherst, Mass., July 1964.

SUTIN, N. – See also CAMPION, R.J.; CONNOCCHIOLI, T.J.; CRAIG, P.P. (Physics); DIEBLER, H.; DULZ, G.; NANCOLLAS, G.H.

TANAKA, S. – See CUMMING, J.B.; KATCOFF, S.; PORILE, N.T.

TAYLOR, T.I. – See KISTNER, A.M.; RUSH, J.J.
THOMAS, T.D. The analysis of nuclear evaporation spectra. *Nucl. Phys.* **53**, 558 (1964).
THOMAS, T.D. Angular momentum effects in neutron evaporation. *Ibid.*, 577 (1964).
THOMAS, T.D., GIBSON, W.M., AND PERLMAN, M.L. X-rays emitted in coincidence with the fission of Cf^{252}. (A) Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.
THOMAS, T.D. AND VANDENBOSCH, R. Correlation of fission-fragment kinetic-energy fine structure with a semiempirical mass surface. *Phys. Rev.* **133**, B976-82 (1964).
THOMPSON, S.O. AND SCHAEFFER, O.A. Search for chlorine-36 in Pacific red clays. (A) Presented at Planetary Sciences Meeting, Washington, April 1964.
THOMPSON, S.O. – See also SCHAEFFER, O.A.
THURBER, D.L. – See FANALE, F.P.
TIMMONS, R.B. AND WESTON, R.E. JR. The relative rates of reaction of bromine atoms with isotopic hydrogen molecules. *J. Chem. Phys.* **41**, 1654-61 (1964).
TIMMONS, R.B. AND WESTON, R.E. JR. The relative rates of reaction of isotopic hydrogen molecules with bromine atoms. (A) Presented at Am. Chem. Soc. Meeting, Denver, Jan. 1964.
TIMMONS, R.B. – See also BIELSKI, B.H.J.
VANDENBOSCH, R. – See THOMAS, T.D.
VAN HOOK, W.A. – See STERN, M.J.
WAMPLER, J.M. AND BRILL, R.H. A preliminary investigation of the usefulness of lead isotopic analysis in archeologic studies. (A) Presented at Am. Geophys. Union Meeting, Washington, April 1964.
WESTON, R.E. JR. AND HEINZINGER, K. Hydrogen isotope fractionation between water vapor and electrolyte solutions. (A) Presented at IAEA Symp. Isotope Mass Effects in Chemistry and Biology, Vienna, Dec. 1963.
WESTON, R.E. JR. – See also HEINZINGER, K.; KLEIN, F.S.; TIMMONS, R.B.
WILLI, A.V. Die Bedeutung der Solvatation von Gruppen mit Ionenladungen in organischen Verbindungen für die Substituenteneffekte auf chemische Gleichgewichte und Reaktionsgeschwindigkeiten. *Chimia* **18**, 107-10 (1964).
WILLI, A.V. AND WOLFSBERG, M. Theoretical calculations of kinetic isotope effects for some nucleophilic substitutions of methyl iodide. Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.
WITHNELL, R. An automatic control system for triple distilled water. (N) Submitted to *Anal. Chem.*
WITHNELL, R. Improvements in techniques for 4π counting. *Nucl. Instr. Methods* **28**, 260 (1964).
WOLF, A.P. The reactions of energetic tritium and carbon atoms with organic compounds. In *Advances in Physical Organic Chemistry*, pp. 201-77, V. Gold, Editor, Academic, London, 1964.
WOLF, A.P. AND STÖCKLIN, G. The reactions of energetic carbon atoms with simple alkanes. Evidence for insertion reaction by methyne. (A) Presented at Am. Chem. Soc. Meeting, Denver, Jan. 1964.
WOLF, A.P. – See also DIEHN, B; MULLEN, R.T.; OAE, S.; STÖCKLIN, G.; WYNBERG, H.
WOLFSBERG, M. AND STERN, M.J. Secondary isotope effects as probes for force constant changes. *Pure Appl. Chem.* **8**, 325-38 (1964).
WOLFSBERG, M. AND STERN, M.J. Validity of some approximation procedures used in the theoretical calculation of isotope effects. *Ibid.*, 225-42.
WOLFSBERG, M. – See also LIFSHITZ, C.; STERN, M.J.; WILLI, A.V.
WYNBERG, H. AND WOLF, A.P. The rearrangement of diphenyl. (L) *J. Am. Chem. Soc.* **85**, 3308 (1963).
WYTTENBACH, A. – See CUMMING, J.B.; KATCOFF, S.
ZAVITSAS, A.A. *t*-Butyl hypochlorite chlorinations of hydrocarbons. The role of chlorinated solvents. (N) *J. Org. Chem.* (in press).
ZAVITSAS, A.A. AND SELTZER, S. The secondary α-deuterium kinetic isotope effect on the formation of methyltrideuteriomethylphenylcarbinyl hypochlorite. (A) Presented at Am. Chem. Soc. Meeting, Denver, Jan. 1964.
ZAVITSAS, A.A. AND SELTZER, S. The transition state in methyl radical formation. The α-deuterium effect. (L) *J. Am. Chem. Soc.* **86**, 1265-7 (1964).
ZAVITSAS, A.A. AND SELTZER, S. The transition state in methyl radical formation. The secondary α-deuterium isotope effect. *J. Am. Chem. Soc.* **86**, 3836-40 (1964).

Information Division

COMSTOCK, M. Bubble chambers – Bibliography. Informal Report BNL 8083.
COMSTOCK, M. AND LEDERMAN, L.M. *Muon Bibliography.* BNL 809 (L-342), April 1963.
PULESTON, D. Brookhaven National Laboratory – Seventeen years of scientific progress. *Long Island Commercial Review*, pp. 26-7, March 31, 1964.

Instrumentation and Health Physics Department

BAKER, L.A., FERRARO, C. JR., AND SCHLAFKE, A.P. JR. Cryogenic safety at Brookhaven National Laboratory. *Proc. 4th World Congr. Prevention of Occupational Accidents and Diseases, London, July 1964* (in press).
CLARK, D.O. AND DISTENFELD, C. New monitoring means for airborne tritium determination. Presented at Health Phys. Soc. Meeting, New York, June 1963.
COWAN, F.P. Personnel dosimetry of very high energy radiations. In *Personnel Dosimetry Techniques for External Radiation: Their Application in Nuclear Installations (Proc. Symp., Madrid, April 1963)*, pp. 273-82, European Nuclear Energy Agency, OECD, Paris, 1963.
COWAN, F.P. Ultra-high-energy radiation and uncommon types of particles. In *Radiation Dosimetry*, Chapter 28, F.H. Attix and W.C. Roesch, Editors, Academic, New York (in press).
COWAN, F.P., PHILLIPS, L.F., AND KING, R.J. Some dosimetry problems of the Alternating Gradient Synchrotron (AGS). *Health Phys.* **10**, 33-40 (1964).
COWAN, F.P. – See also PHILLIPS, L.F.
DISTENFELD, C. – See CLARK, D.O.
FERRARO, C. JR. – See BAKER, L.A.
FISCHER, J. High voltage pulse probe of fast rise time for spark chambers. (N) *Rev. Sci. Instr.* **35**, 125-6 (1964).

FISCHER, J., COLLINS, G.B., AND HIGINBOTHAM, W.A. Characteristics of a digitized discharge hodoscope. In *Électronique Nucléaire (Proc. Intern. Symp., Paris, Nov. 1963)*, pp. 57-64, OECD, McGraw-Hill, New York, 1963.

FISCHER, J. AND HIGINBOTHAM, W.A. Spark chamber research and development at the Instrumentation Division of Brookhaven National Laboratory. Informal Report BNL 7376.

FOELIX, C.F. AND GEMMELL, L. The use of activated charcoal iodine monitors during and following a release of fission product iodines. In *8th AEC Air Cleaning Conf., Oak Ridge National Laboratory, Oct. 1963*, pp. 629-37, TID-7677, 1963.

FOELIX, C.F. AND HULL, A.P. Monitoring the cooling air effluent from the Brookhaven Graphite Research Reactor at the point of release and in the environment. *Intern. Conf. Radioactive Pollution of Gaseous Media, Saclay, France, Nov. 1963* (in press).

GEMMELL, L. Decontamination methods, equipment and materials. *Proc. Symp. Radiation Accidents and Emergencies in Medicine, Research and Industry, Chicago, Dec. 1963* (in press).

GEMMELL, L. AND PEARSALL, S.G. Transport of fission products through the soil following injection from a well and methods used for removal. In *Intern. Colloq. Retention and Migration of Radioactive Ions in Soils, Paris, Oct. 1962*, pp. 199-206, TD 812, 1962.

GEMMELL, L. – See also FOELIX, C.F.

HIGINBOTHAM, W.A. – See FISCHER, J.; FOLEY, K.J. (Physics).

HULL, A.P. *1962 Environmental Radiation Levels at Brookhaven National Laboratory*. BNL 807 (T-310), May 1963.

HULL, A.P. Vegetation retention and vegetation-milk ratios of fallout I^{131}. *Health Phys.* **9**, 1173-7 (1963).

HULL, A.P. AND SMITH, M.E. *An Evaluation of the Environmental Significance of a Postulated Fuel Element Failure Incident at the Brookhaven Graphite Research Reactor*. BNL 819 (T-318), June 1963.

HULL, A.P. – See also FOELIX, C.F.

JACOBS, J.F. Ferroelectric hysteresis bridge. Informal Report BNL 8006.

KING, R.J. – See COWAN, F.P.; PHILLIPS, L.F.; POLK, I. (Accelerator).

LLACER, J. Study of surface effects in thick lithium drifted silicon radiation detectors. *IEEE Trans. Nucl. Sci.* **NS-11**, No. 3, 221-31 (1964).

MERRITT, F. – See SUGARMAN, R.

MILLER, G.L. AND RADEKA, V. Analogue multiplication with field-effect transistors. *Instrumentation Techniques in Nuclear Pulse Analysis, Natl. Acad. Sci.–Natl. Res. Council Publ.* **1184**, 104-111 (1963).

MILLER, G.L. AND RADEKA, V. Fast-analogue multipliers with field-effect transistors. (A) Presented at IEEE–PTGNS Intern Symp. Plasma Phenomena and Measurements, San Diego, Oct. 1963.

MILLER, G.L., WAGNER, S., AND YUAN, L.C.L. Investigations on lithium-drift solid-state detectors for high-energy particle detection. *Nucl. Instr. Methods* **20**, 303-5 (1963).

MILLER, G.L. – See also TEPPER, L.

NIELL, A.M. – See ROBERTSON, J.S. (Medical).

PANDARESE, F. Behavior of tunnel diode amplitude discriminators. *IEEE Trans. Nucl. Sci.* **NS-11**, No. 2, 16-23 (1964).

PATE, H. – See YONDA, A.

PEARSALL, S.G. – See GEMMELL, L.

PHILLIPS, L.F., KING, R.J., AND COWAN, F.P. Depth-dose studies with 3-BeV and 33-BeV proton beams. *Nucleonics* **21**, No. 12, 55-8 (1963).

PHILLIPS, L.F. – See also COWAN, F.P.

POTTER, D. A digital data handling system for high energy physics experiments. Informal Report BNL 7852.

POTTER, D. – See also FOLEY, K.J. (Physics).

RADEKA, V. Fast analogue multipliers with field-effect transistors. *IEEE Trans. Nucl. Sci.* **NS-11**, No. 1, 302-7 (1964).

RADEKA, V. Fast decimal counting with binary-decimal logic. *IEEE Trans. Nucl. Sci.* **NS-11**, No. 1, 296-301 (1964).

RADEKA, V. The field-effect transistor – Its characteristics and applications. *IEEE Trans. Nucl. Sci.* **NS-11**, No. 3, 358-64 (1964).

RADEKA, V. Field-effect transistors in charge sensitive amplifiers. *Instrumentation Techniques in Nuclear Pulse Analysis, Natl. Acad. Sci.–Natl. Res. Council Publ.* **1184**, 70-8 (1963).

RADEKA, V. – See also MILLER, G.L.

RANKOWITZ, S. – See CHRIEN, R.E. (Physics).

RAYNOR, G.S. AND SMITH, M.E. *A Diffusion-Deposition Tracer System*. BNL 859 (T-343), April 1964.

ROGERS, E.J. Accurate binary levels in a clamped circuit. *Electron. Design* **12**, No. 9, 91 (1964).

ROGERS, E.J. Current feedback eliminates errors due to contact voltage drops. Informal Report BNL 7546.

ROGERS, E.J. Detailed description of electronic microscope stage manipulator. Informal Report BNL 7185.

ROGERS, E.J. Low-cost temperature control provides high stability. *Electron. Design* **11**, No. 22, 77-8 (1963).

ROGERS, E.J. Method for comparing small ac voltages in the presence of large dc components. *Rev. Sci. Instr.* **35**, 130-2 (1964).

ROGERS, E.J. AND TONNA, E.A. Electronically controlled stage for systematic scanning of microscopic areas. *IEEE Trans. Bio-Med. Electron.* **BME-10**, No. 4, 163-70 (1963).

SCHLAFKE, A.P. JR. – See BAKER, L.A.

SINGER, I.A. Wind gust spectra. *Ann. N.Y. Acad. Sci.* **116**, 116-34 (1964).

SMITH, M.E. Meteorological tools for air pollution control. *J. Air Pollution Control Assoc.* **14**, 80-2 (1964).

SMITH, M.E. The status of meteorological knowledge as a factor in air pollution control. *Proc. Natl. Conf. Air Pollution, Washington, Nov. 1962, U.S. Dept. Health Educ. Welfare Publ.* **1022**, 260-6 (1963).

SMITH, M.E. – See also RAYNOR, G.S.; HULL, A.P.

SPINRAD, R.J. Analog-to-digital conversion of any k out of n signals. (N) *Rev. Sci. Instr.* **34**, 1269-70 (1963).

SPINRAD, R.J. Computer-centered data handling systems. *IEEE Trans. Nucl. Sci.* **NS-11**, No. 3, 324-30 (1964).

SPINRAD, R.J. Computers or multichannel analyzers? *Nucleonics* **21**, No. 12, 46-9 (1963).

SPINRAD, R.J. Data systems for multiparameter analysis. *Ann. Rev. Nucl. Sci.* **14** (in press).

SPINRAD, R.J. Digital systems for data handling. Chapter in *Progress in Nuclear Techniques and Instrumentation*, F.J.M. Farley, Editor, North-Holland, Amsterdam (in press).

SPINRAD, R.J. Machine recognition of hand printing. Submitted to *Inform. and Control.*

SPINRAD, R.J. Multiple neutron spectrometer control system. (A) Presented at Conf. Automatic Acquisition and Reduction of Nuclear Data, Karlsruhe, West Germany, July 1964.

SPINRAD, R.J. – See also CHRIEN, R.E. (Physics); KANE, J.V. (Physics).

SUGARMAN, R. AND MERRITT, F. Reflection coefficient of 125-ohm amphenol connectors. Informal Report BNL 7761.

TEPPER, L., MILLER, G.L., AND KYCIA, T. A beam profile indicator with solid state detectors. *IEEE Trans. Nucl. Sci.* **NS-11**, No. 3, 431-40 (1964).

WAGNER, S. – See MILLER, G.L.; MOLLENAUER, J.F. (Chemistry).

YONDA, A., FILMER, D.L., PATE, H., ALONZO, N., AND HIRS, C.H.W. A digital procedure for the computation of amino acid analyzer data. *Anal. Biochem.* (in press).

Medical Department

ALCOBER, V. – See ARCHAMBEAU, J.O.; LIPPINCOTT, S.W.

AMATO, C.G. – See MALSKY, S.J.

ANDREWS, G. – See FLIEDNER, T.M.

APONTE, G. – See BOND, V.P.

ARCHAMBEAU, J.O., ALCOBER, V., CALVO, W. AND BRENNEIS, H. Biological effects of thermal neutrons and the $B^{10}(n,\alpha)Li^7$ reaction. In *Biological Effects of Neutron and Proton Irradiations (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 2, pp. 55-72, IAEA, Vienna, 1964.

ARCHAMBEAU, J.O., DREW, R.M., AND ROBERTSON, J.S. Dose-survival curves for HeLa cell cultures using thermal neutrons and the $B^{10}(n,\alpha)Li^7$ reaction. In *Biological Effects of Neutron and Proton Irradiations. (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 1, pp. 343-59, IAEA, Vienna, 1964.

ARCHAMBEAU, J.O. AND WILDERMUTH, O. Comfort and support of the cancer patient. *Radiol. Clin.* **33**, 13-21 (1964).

ARONOW, S. – See LIPPINCOTT, S.W.

ARONSON, R.B. – See TONNA, E.A.

ATKINS, H.L. Biological application of neutron radiography. (A) Presented at Soc. for Nondestructive Testing Meeting, Philadelphia, Oct. 1964.

ATKINS, H.L. AND TRETTER, P. Radiation myelopathy: Time-dose considerations. (A) Presented at 7th Symp. Neuroradiologicum, New York, Sept. 1964.

BATEMAN, J.L. AND BOND, V.P. The effects of radiations of different LET on early responses in the mammal. *Ann. N.Y. Acad. Sci.* **114**, 32-47 (1964).

BATEMAN, J.L., BOND, V.P., AND ROSSI, H.H. Lens opacification in mice exposed to monoenergetic fast neutrons. In *Biological Effects of Neutron and Proton Irradiations (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 2, pp. 321-36, IAEA, Vienna, 1964.

BATEMAN, J.L., BOND, V.P. AND ROSSI, H.H. Spermatogonia depletion with radiations of different LET. (A) *Radiation Res.* **22**, 168 (1964).

BATEMAN, J.L. – See also DAVIES, D.R. (Biology); SMITH, H.H. (Biology).

BOND, V.P. Biomedical reactor investigations. *Proc. 75th Anniv. Symp. Georgia Institute of Technology, Nov. 1963* (in press).

BOND, V.P. Introductory remarks (Chemistry in Medicine Symp.). *Federation Proc.* **23**, 585 (1964).

BOND, V.P., CRONKITE, E.P., AND CONARD, R.A. Acute whole-body radiation injury: Pathogenesis, pre- and post-radiation protection. In *Atomic Medicine*, 4th Ed., pp. 203-37, C.H. Behrens, Editor, Williams & Wilkins, Baltimore, 1964.

BOND, V.P., CRONKITE, E.P., SHELLABARGER, C.J., AND APONTE, G. Radiation-induced mammary gland neoplasia in the rat. In *Mammalian Cytogenetics and Related Problems in Radiobiology (Proc. Symp., Rio de Janeiro, Oct. 1962)*, pp. 361-82, Pergamon, London, 1964.

BOND, V.P. AND FEINENDEGEN, L.E. Exchange of nucleic acid precursors between human cancer cells in culture. *Federation Proc.* **23**, 634-9 (1964).

BOND, V.P., FEINENDEGEN, L.E., HEINZE, E., AND COTTIER, H. Distribution of transfused tritiated cytidine labeled leukocytes and red cells in the bone marrow of normal and irradiated rats: *Ann. N.Y. Acad. Sci.* **113**, 1009-19 (1964).

BOND, V.P. AND FLIEDNER, T.M. Radiobiological basis for the whole-body radiation syndrome. Submitted to *Strahlentherapie.*

BOND, V.P. AND ROBERTSON, J.S. Comparison of the mortality response of different mammalian species to x rays and fast neutrons. In *Biological Effects of Neutron and Proton Irradiations (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 2, pp. 365-77, IAEA, Vienna, 1964.

BOND, V.P. – See also BATEMAN, J.L.; CONARD, R.A.; CRONKITE, E.P.; FEINENDEGEN, L.E.; FLIEDNER, T.M.; JACOBS, G.J.; JANSEN, C.R.; JESSEPH, J.E.; KEISER, G.; KILLMANN, S.A.; MALSKY, S.J.; NIELSEN, N.O.; ODARTCHENKO, N.; YAMAMOTO, Y.L.

BORG, D.C. Free radicals from imipramine. *Biochem. Pharmacol.* (in press).

BORG, D.C. Free radicals from salicylate. Submitted to *Biochim. Biophys. Acta.*

BORG, D.C. An improved flow system for electron paramagnetic resonance spectrometry of aqueous solutions. *Nature* **201**, 1087-90 (1964).

BORG, D.C. Using the atom in basic medical research. *Proc. 1963 Natl. Youth Conf. on the Atom, Chicago, Nov. 1963* (in press).

BORG, D.C. AND CONARD, R.A. Activation analysis of Hiroshima soil samples with estimations of residual activity following atom bomb detonation in August 1945. Informal Report BNL 7976.

BOZZO, S. – See COHN, S.H.

BRENNEIS, H. – See ARCHAMBEAU, J.O.

BROWN, R.R. – See HANKES, L.V.

BRYANT, B.J. – See KEISER, G.

CALVO, W. – See ARCHAMBEAU, J.O.; LIPPINCOTT, S.W.

CANNON, B. – See CONARD, R.A.

CARSON, P.E. – See VAN SLYKE, D.D.

CLIFFORD, D.H. Acute barbiturate intoxication. In *Current Veterinary Therapy, 1964-65,* pp. 451-5, R.W. Kirk, Editor, Saunders, Philadelphia, 1964.

COHN, S.H. The whole-body counter in medical research and diagnosis. In *Progress in Atomic Medicine,* J. Lawrence, Editor, Grune & Stratton, New York (in press).

COHN, S.H., BOZZO, S., GLATSTEIN, N., CONSTANTINIDES, C., LITVAK, J., AND GUSMANO, E.A. Formulation of a compartmental model in a study of partial parathyroid deficiency. *Metab., Clin. Exptl.* (in press).

COHN, S.H. AND GUSMANO, E.A. Determination of body burdens of radionuclides by computer analysis of gamma-ray spectral data. *Health Phys.* (in press).

COHN, S.H. AND GUSMANO, E.A. Uptake and transfer of fallout I^{131} in pregnant women. *Health Phys.* **9**, 1267-9 (1963).

COHN, S.H., GUSMANO, E.A., LIPPINCOTT, S.W., AND ROBERTSON, J.S. *In-vivo* measurement of Thorotrast in liver and spleen by gamma spectrometric analysis. (A) *Radiation Res.* **22**, 177 (1964).

COHN, S.H., ROBERTSON, J.S., GUSMANO, E.A., AND CONARD, R.A. Measurement of Sr^{90} and Cs^{137} in a population exposed to fallout. (A) Presented at IAEA Symp. Assessment of Radioactive Body Burdens in Man, Heidelberg, West Germany, May 1964.

COHN, S.H. – See also PRICE, D.C.; ROBERTSON, J.S.; SCHIFFER, L.M.

COMMERFORD, S.L. The effect of gamma irradiation on the viability of cells with a relatively long life span. (A) *Radiation Res.* **22**, 178 (1964).

COMMERFORD, S.L. – See also HUGHES, W.L.

CONARD, R.A. Indirect effect of x-radiation on bone growth in rats. *Ann. N.Y. Acad. Sci.* **114**, 335-8 (1964).

CONARD, R.A.., CRONKITE, E.P., AND BOND, V.P. Fallout radiation: Effects on the skin. In *Atomic Medicine,* 4th Ed., pp. 259-79, C.H. Behrens, Editor, Williams & Wilkins, Baltimore, 1964.

CONARD, R.A., MEYER, L.M., SUTOW, W.W., MOLONEY, W.C., CANNON, B., HICKING, A., AND RIKLON, E. Medical survey of the people of Rongelap and Utirik Islands, nine years after exposure to fallout radiation (March 1963). Informal Report BNL 7766.

CONARD, R.A. – See also BOND, V.P.; BORG, D.C.; COHN, S.H.; CRONKITE, E.P.; LYON, H.W.

CONSTANTINIDES, C. – See COHN, S.H.

CORCORAN, C. – See LIPPINCOTT, S.W.

COTTIER, H., CRONKITE, E.P., JANSEN, C.R., RAI, K.R., SINGER, S., AND SIPE, R. Studies on lymphocytes. III. Effects of extracorporeal irradiation of the circulating blood upon the lymphoreticular organs in the calf. *Blood* **24**, 241-53 (1964).

COTTIER, H., ODARTCHENKO, N., KEISER, G., HESS, M., AND STONER, R.D. Incorporation of tritiated nucleosides and amino acids into lymphoid and plasmocytoid cells during secondary response to tetanus toxoid in mice. *Ann. N.Y. Acad. Sci.* **113**, 612-26 (1964).

COTTIER, H. – See also BOND, V.P.; CRONKITE, E.P.; HESS, M.W.; KEISER, G.; NIELSEN, N.O.; ODARTCHENKO, N.

COTZIAS, G.C. Conclusion of Colloquium. In *L'Analyse par Radioactivation et Ses Applications aux Sciences Biologiques (Proc. 3e Colloq. Intern. Biol. Saclay, Saclay, France, Sept. 1963)*, pp. 405-8, Presses Universitaires de France, Vendôme, 1964.

COTZIAS, G.C. Heavy metals and the brain: Modern techniques for an ancient puzzle. (A) In *First Asian and Oceanian Congress,* Tokyo, p. 155 (1962).

COTZIAS, G.C. Manganese, melanins and the extrapyramidal system. *Proc. 2nd Veterans Administration Symp. on Parkinsonism, Washington, Nov. 1963* (in press).

COTZIAS, G.C. Der Mangan Metabolismus und seine Störungen. *Proc. German Soc. Internal Medicine, Wiesbaden, West Germany, April 1964* (in press).

COTZIAS, G.C. *Trace Metals: Essential or Detrimental to Life, Brookhaven Lecture Series No. 26, April 10, 1963.* BNL 828 (T-323).

COTZIAS, G.C. Transport, homeostasis and specificity in trace metal metabolism. *Brit. J. Nutrition* (in press).

COTZIAS, G.C. AND PAPAVASILIOU, P.S. Primordial homeostasis in a mammal as shown by the control of manganese. *Nature* **201**, 828-9 (1964).

COTZIAS, G.C. AND PAPAVASILIOU, P.S. The specificity of the zinc pathway through the body: Homeostatic considerations. *Am. J. Physiol.* **206**, 787-92 (1964).

COTZIAS, G.C., PAPAVASILIOU, P.S., AND MILLER, S.T. Manganese in melanin. *Nature* **201**, 1228-9 (1964).

COTZIAS, G.C., PAPAVASILIOU, P.S., AND MILLER, S.T. Neutron activation analysis: Clinical and biological studies of manganese. In *L'Analyse par Radioactivation et Ses Applications aux Sciences Biologiques (Proc. 3e Colloq. Intern. Biol. Saclay, Saclay, France, Sept. 1963),* pp. 287-306, Presses Universitaires de France, Vendôme, 1964.

COTZIAS, G.C., PAPAVASILIOU, P.S., VAN WOERT, M.H., AND SAKAMOTO, A. Melanogenesis and extrapyramidal diseases. *Federation Proc.* **23**, 713-18 (1964).

COTZIAS, G.C. AND VAN WOERT, M.H. Manganese poisoning: New insights. *Proc. 1st Pan American Congr. Neurology, Lima, Oct. 1963* (in press).

COTZIAS, G.C. – See also PATTEN, B.M.

CRONKITE, E.P. Diagnosis of radiation injury. Submitted to *Nucl. News.*

CRONKITE, E.P. The diagnosis, treatment and prognosis of human radiation injury from whole-body exposure. *Ann. N.Y. Acad. Sci.* **114**, 341-9 (1964).

CRONKITE, E.P. Enigmas underlying study of hemopoietic cell proliferation. *Federation Proc.* **23**, 649-61 (1964).

CRONKITE, E.P. Erythropoietic cell proliferation in man. *Proc. Conf. Disorders of Erythropoiesis, Boston City Hospital, June 1964* (in press).

CRONKITE, E.P. Extracorporeal irradiation of the blood in the study of lymphocyte proliferation and function. *Proc. Symp. Honoring Prof. Heilmeyer's Birthday, Grundlagenforschung in ihrer Bedeutung für die klinische Medizin, Freiburg, West Germany, March 1964* (in press).

CRONKITE, E.P. Radiation injury. In *Principles of Internal Medicine,* 5th Ed., Chapter 246, T.R. Harrison, Editor, McGraw-Hill, New York (in press).

CRONKITE, E.P. Radiation injury: The acute and late effects, a problem in industrial and military medicine. *Maryland State Med. J.,* pp. 1-8 (Aug. 1963).

CRONKITE, E.P., BOND, V.P., AND CONARD, R.A.. Diagnosis and therapy of acute radiation injury. In *Atomic Medicine,* 4th Ed., pp. 238-50, C.H. Behrens, Editor, Williams & Wilkins, Baltimore, 1964.

CRONKITE, E.P. AND FLIEDNER, T.M. Granulocytopoiesis (concluded). *New Engl. J. Med.* **270**, 1403-8 (1964).

CRONKITE, E.P., JANSEN, C.R., COTTIER, H., RAI, K., AND SIPE, C.R. Lymphocyte production measured by extracorporeal irradiation, cannulation, and labeling techniques. *Ann. N.Y. Acad. Sci.* **113**, 566-77 (1964).

CRONKITE, E.P. – See also BOND, V.P.; CONARD, R.A.; COTTIER, H.; FEINENDEGEN, L.E.; FLIEDNER, T.M.; JACOBS, G.J.; KILLMANN, S.A.; KUHL, O.A. (Nuclear

Engineering); MEYER, L.M.; PRICE, D.C.; RUBINI, J.R.; SCHIFFER, L.M.; TONNA, E.A.

CUTTNER, J. – See SCHIFFER, L.M.

DAHL, L.K. Effects of chronic excess salt ingestion. Experimental hypertension in the rat: Correlation with human hypertension. *Proc. Intern. Symp. Epidemiology of Hypertension, Chicago, Feb. 1964* (in press).

DAHL, L.K. Studies on the role of salt and genetics in hypertension. *Acad. Med. N. J. Bull.* (in press).

DAHL, L.K., HEINE, M., AND TASSINARI, L. Effects of chronic excess salt ingestion. Vascular reactivity in two strains of rats with opposite genetic susceptibility to experimental hypertension. *Circulation* **30**, *Suppl. 2*, 11-22 (1964).

DAHL, L.K. AND SCHACKOW, E. Effects of chronic excess salt ingestion. Experimental hypertension in the rat. *Can. Med. Assoc. J.* **90**, 155-60 (1964).

DE MEUTTER, R.C. – See SHREEVE, W.W.

DREW, R.M., PAINTER, R.B., AND FEINENDEGEN, L.E. Oxygen inhibition of nucleic acid synthesis in HeLa S_3 cells. *Exptl. Cell Res.* (in press).

DREW, R.M. – See also ARCHAMBEAU, J.O.; PAINTER, R.B.

FARR, L.E. – See LIPPINCOTT, S.W.

FEINENDEGEN, L.E. AND BOND, V.P. Zur RNS-Syntheses im Chromatin und im Nukleolus der menschlichen Krebszelle HeLa-S_3 in Kultur. Submitted to *Atomkernenergie.*

FEINENDEGEN, L.E., BOND, V.P., CRONKITE, E.P., AND HUGHES, W.L. Nucleic acid metabolism in bone marrow cells studied with tritiated nucleosides. (A) Presented at 9th Congr. European Soc. Hematology, Lisbon, Aug. 1963.

FEINENDEGEN, L.E., BOND, V.P., CRONKITE, E.P., AND HUGHES, W.L. Reutilization of DNA-thymine, and conversion of RNA-pyrimidines for DNA-thymine, in normal rat bone marrow, studies with tritiated nucleosides. Preprint EUR 1814.e, Euratom; *Proc. 9th Congr. European Soc. Hematology, Lisbon, Aug. 1963* (in press).

FEINENDEGEN, L.E., BOND, V.P., CRONKITE, E.P., AND HUGHES, W.L. RNA turnover in normal rat bone marrow. *Ann. N.Y. Acad. Sci.* **113**, 727-41 (1964).

FEINENDEGEN, L.E. – See also BOND, V.P.; DREW, R.M.; NIELSEN, N.O.; ODARTCHENKO, N.; YAMAMOTO, Y.L.

FISCHER, D.S. AND PRICE, D.C. A simple serum iron method using the new sensitive chromogen tripyridyl-s-triazine. *J. Clin. Chem.* **10**, 21-31 (1964).

FLIEDNER, T.M., ANDREWS, G., CRONKITE, E.P., AND BOND, V.P. Early and late cytological effects of whole-body irradiation on human marrow. *Blood* **23**, 471-87 (1964).

FLIEDNER, T.M. AND CRONKITE, E.P. Hematological effects of whole-body irradiation. *Proc. 2nd Ann. Conf. Scientists on Survival, New York, June 1963* (in press).

FLIEDNER, T.M. AND CRONKITE, E.P. Studies on the transit-time and fate of neutrophilic granulocytes in man. (A) Presented at Am. Soc. Hematol. Meeting, Washington, Dec. 1963.

FLIEDNER, T.M., CRONKITE, E.P., AND BOND, V.P. Studies on myelocytic cell turnover in bone marrow and blood. *Nucl. Med.* **2**, *Suppl. 1*, 279-92 (1962).

FLIEDNER, T.M., CRONKITE, E.P., KILLMANN, S.A., AND BOND, V.P. Granulocytopoiesis. II. Emergence and pattern of labeling of neutrophilic granulocytes in human beings. *Blood* (in press).

FLIEDNER, T.M., CRONKITE, E.P., AND ROBERTSON, J.S. Granulocytopoiesis. I. Senescence and random loss of neutrophilic granulocytes in human beings. *Blood* **24**, 402-14 (1964).

FLIEDNER, T.M., KESSE, M., CRONKITE, E.P. AND ROBERTSON, J.S. Cell proliferation in germinal centers of the rat spleen. *Ann. N.Y. Acad. Sci.* **113**, 578-94 (1964).

FLIEDNER, T.M., THOMAS, E.D., MEYER, L.M., AND CRONKITE, E.P. The fate of transfused H^3-thymidine-labeled bone marrow cells in irradiated recipients. *Ann. N.Y. Acad. Sci.* **114**, 510-27 (1964).

FLIEDNER, T.M. – See also BOND, V.P.; CRONKITE, E.P.; KILLMANN, S.A.: MEYER, L.M.

FORSYTH, E.M. – See PRICE, D.C.

GHOSE, A., SHREEVE, W.W., SHIGETA, Y., AND SCHWARTZ, I.L. Incorporation of tritium into human plasma triglycerides from glucose-1-H^3 and lactic acid-2-H^3. *Nature* **201**, 722-3 (1964).

GITLIN, D. – See HUGHES, W.L.

GLASSFORD, K.F. – See LYON, H.W.

GLATSTEIN, N. – See COHN, S.H.

GUSMANO, E.A. – See COHN, S.H.

HALE, W.M. AND STONER, R.D. Secondary tetanus antitoxin responses in mice elicited prior to irradiation. *Radiation Res.* **20**, 383-98 (1963).

HAMMERSTROM, R.A. AND STONER, R.D. Isolation of leukocytes from mouse blood. *J. Lab. Clin. Med.* **62**, 985-8 (1963).

HANKES, L.V. Carbonyl-C^{14}-labeled DL-kynurenine. Submitted to *Biochem. Prep.*

HANKES, L.V. The metabolism of DL-tryptophan-7a-C^{14} in rats. (A) *Federation Proc.* **23**, 421 (1964).

HANKES, L.V., BROWN, R.R., SCHMAELER, M., AND LIPPINCOTT, S.W. Metabolism of 3-hydroxyanthranilic acid–carboxyl-C^{14} in the human. *Proc. Soc. Exptl. Biol. Med.* **115**, 1083-8 (1964).

HANKES, L.V. AND SCHMAELER, M. Carrier and overloading effects on the metabolism of DL-tryptophan-7a-C^{14}. Submitted to *Biochem. Biophys. Res. Commun.*

HANKES, L.V. AND SCHMAELER, M. Chromatography of tryptophan metabolites. Submitted to *J. Chromatog.*

HANKES, L.V., SCHMAELER, M., AND STONER, R.D. Metabolism of C^{14}-carboxyl-labeled 3-hydroxyanthranilic acid in normal and neoplastic mice. *Nature* **200**, 676-77 (1963).

HEINE, M. – See DAHL, L.K.

HEINZE, E. – See BOND, V.P.

HESS, M.W., COTTIER, H., AND STONER, R.D. Antibody responses in thymectomized mice. (A) Presented at 10th Congr. Intern. Soc. Hematology, Stockholm, Aug. 30 – Sept. 4, 1964.

HESS, M.W. AND STONER, R.D. Enhanced antitoxin responses in irradiated mice elicited with complexes of active tetanus toxin and specific antibody. (A) *Radiation Res.* **22**, 194 (1964).

HESS, M.W. – See also COTTIER, H.

HICKING, A. – See CONARD, R.A.

HUGHES, W.L., COMMERFORD, S.L., GITLIN, D., KRUEGER, R.C., SCHULTZE, B., SHAH, V., AND REILLY, P. Deoxyribonucleic acid metabolism *in vivo*. I. Cell proliferation and death as measured by incorporation and elimina-

tion of iododeoxyuridine. *Federation Proc.* **23**, 640-8 (1964).

HUGHES, W.L. – See also FEINENDEGEN, L.E.

HWANG, W.S.S. AND TONNA, E.A. An autoradiographic analysis of the labeling indices and migration rates of the cellular component of mouse incisors using tritiated thymidine (H^3TDR). *J. Dental Res.* (in press).

JACOBS, G.J., LYNCH, F.X., CRONKITE, E.P., AND BOND, V.P. Human radiation – A correlation of leukocyte depression with mortality in the Japanese exposed to the atomic bombs. *Miltitary Med.* **128**, 732-9 (1963).

JACOBS, G.J., WALD, N., BOND, V.P., CRONKITE, E.P., WAKISAKA, C., AND LYNCH, F.X. Malignant neoplasia and the initial hematologic response in Japanese exposed to the A-bomb in Hiroshima. *Atomic Bomb Casualty Commission Report* (in press).

JANSEN, C.R., BOND, V.P., RAI, K.R., AND LIPPINCOTT, S.W. Abscopal effects of localized irradiation by accelerator beams. *Ann. N.Y. Acad. Sci.* **114**, 302-15 (1964).

JANSEN, C.R. – See also COTTIER, H., CRONKITE, E.P.; LIPPINCOTT, S.W.

JEE, W.S.S. – See TONNA, E.A.

JESSEPH, J.E., MOORE, W.H., BOND, V.P., AND LIPPINCOTT, S.W. The effects of 2.0 GeV protons in mice. In *Biological Effects of Neutron and Proton Irradiations (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 1, pp. 279-85, IAEA, Vienna, 1964.

JESSEPH, J.E. – See also LIPPINCOTT, S.W.

JOHNSON, H.A. Age and sensitivity to radiation life shortening. *Radiation Res.* **23**, 19-25 (1964).

KEISER, G., BRYANT, B.J., AND BOND, V.P. On the transitional cells in dog bone marrow and blood during the early recovery phase after x-irradiation. (A) *Radiation Res.* **22**, 203 (1964).

KEISER, G., COTTIER, H., ODARTCHENKO, N., AND BOND, V.P. Autoradiographic study on the origin and fate of small lymphoid cells in the dog bone marrow. Effect of femoral artery clamping during *in vivo* availability of H^3-thymidine. *Blood* **24**, 254-66 (1964).

KEISER, G. – See also COTTIER, H.

KELLER, S. – See RUBINI, J.R.

KESSE, M. – See FLIEDNER, T.M.

KILLMANN, S.A., CRONKITE, E.P., FLIEDNER, T.M., AND BOND, V.P. Mitotic indices of human bone marrow cells. III. Duration of some phases of erythrocytic and granulocytic proliferation computed from mitotic indices. *Blood* **24**, 267-80 (1964).

KILLMANN, S.A. – See also FLIEDNER, T.M.

KRUEGER, R.C. – See HUGHES, W.L.

LIPPINCOTT, S.W., CALVO, W., BAKER, C.P., JESSEPH, J.E., JANSEN, C.R., AND FARR, L.E. Effects of heavy high energy charged particles. IV. The fate of giant cells produced in a neoplasm by 20-MeV deuteron bombardment. *Arch. Pathol.* **76**, 543-52 (1963).

LIPPINCOTT, S.W., CORCORAN, C., JANSEN, C.R., JESSEPH, J.E., RAI, K., ARONOW, S., GREENE, M.W., AND SWEET, W.H. Labeling of human globulin with I^{124} for positron scanning of neoplasms. *J. Nucl. Med.* **5**, 193-9 (1964).

LIPPINCOTT, S.W., JESSEPH, J.E., BAKER, C.P., CALVO, W.G., JANSEN, C.R., RAI, K.R., AND ALCOBER, V. Effects of heavy high energy charged particles. II. Primary atypical epithelial hyperplasia in mouse skin following exposure to 10-MeV protons, 20-MeV deuterons or 40-MeV alpha particles. *Arch. Pathol.* **76**, 527-36 (1963).

LIPPINCOTT, S.W., JESSEPH, J.E., CALVO, W.G., AND BAKER, C.P. Progressive epithelial dysplasia in mouse skin irradiated with 10-MeV protons. In *Biological Effects of Neutron and Proton Irradiations (Proc. IAEA Symp., Brookhaven National Laboratory, Oct. 1963)*, Vol. 2, pp. 105-16, IAEA, Vienna, 1964.

LIPPINCOTT, S.W., JESSEPH, J.E., MOORE, W.H., AND STRAUB, R.F. Effects of heavy high energy charged particles. III. *In vivo* activation in mice of C^{12}, N^{14} and O^{16} by bombardment with 2-BeV protons. *Arch. Pathol.* **76**, 537-42 (1963).

LIPPINCOTT, S.W., MOORE, W.H., JESSEPH, J.E., AND CALVO, W. Effects of heavy high energy charged particles. I. Literature review of effects of protons, deuterons and alpha particles in mammals with a theoretical consideration of the negative π meson. *Arch. Pathol.* **76**, 497-526 (1963).

LIPPINCOTT, S.W. – See also COHN, S.H.; HANKES, L.V.; JANSEN, C.R.; JESSEPH, J.E.

LITVAK, J. – See COHN, S.H.

LIVINGSTON, L.M. – See SCHWARTZ, I.L.

LOVE, R.A. Planning for radiation accidents. *Hospitals* **38**, Feb. 16, 1964.

LYNCH, F.X. – See JACOBS, G.J.

LYON, H.W., CONARD, R.A., AND GLASSFORD, K.F. Long-term intraoral findings in humans after exposure to total-body irradiation from sudden radioactive fallout. I. Five-year post-detonation studies. *J. Am. Dental Assoc.* **68**, 50-6 (1964).

MALSKY, S.J., AMATO, C.G., BOND, V.P., ROBERTSON, J.S., AND ROSWIT, B. Inhomogeneity of dose distribution in animals subjected to whole-body irradiation with 250-kVp x rays. *Radiation Res.* **21**, 462-72 (1964).

MARC-AURELE, J. – See SCHWARTZ, I.L.

MEYER, L.M., FLIEDNER, T.M., AND CRONKITE, E.P. Autologous bone marrow transfusion following chemotherapy. *Ann. N.Y. Acad. Sci.* **114**, 499-508 (1964).

MEYER, L.M., SCHIFFER, L.M., AND CRONKITE, E.P. Effect of prior injection of analogues of vitamin B_{12} on plasma clearance of intravenously injected Co^{57} vitamin B_{12}. (A) Presented at 9th Congr. European Soc. Hematology, Lisbon, Aug. 1963.

MEYER, L.M., SCHIFFER, L.M., AND CRONKITE, E.P. Plasma clearance of vitamin B_{12}. I. Effect of prior hydroxocobalamin in chronic myelocytic leukemia and normal subjects. *J. Lab. Clin. Med.* (in press).

MEYER, L.M. – See also CONARD, R.A.; FLIEDNER, T.M.; SCHIFFER, L.M.

MILLER, S.T. – See COTZIAS, G.C.

MOLONEY, W.C. – See CONARD, R.A.

NIELSEN, N.O. The effect of whole-body x-irradiation on glucose tolerance in the dog. *Radiation Res.* **21**, 180-5 (1964).

NIELSEN, N.O., FEINENDEGEN, L.E., BOND, V.P., ODARTCHENKO, N., AND COTTIER, H. *In vitro* uptake of tritiated thymidine by erythrocytic precursors following hemorrhage in the dog. *Proc. Soc. Exptl. Biol. Med.* **116**, 498-501 (1964).

ODARTCHENKO, N., BOND, V.P., FEINENDEGEN, L.E., AND COTTIER, H. Kinetics of erythroblastic cell populations

in the dog, studied with tritiated thymidine. In *Proc. 9th Congr. Intern. Soc. Hematology, Mexico City, Sept. 1963,* Vol. 3, pp. 267-72, Grune & Stratton, New York, 1964.

ODARTCHENKO, N., COTTIER, H., FEINENDEGEN, L.E., AND BOND, V.P. Evaluation of mitotic time *in vivo*, using tritiated thymidine as a cell marker: Successive labeling with time of separate mitotic phases. *Exptl. Cell Res.* 35, 402-11 (1964).

ODARTCHENKO, N., COTTIER, H., FEINENDEGEN, L.E., AND BOND, V.P. Mitotic delay in more mature erythroblasts of the dog, induced *in vivo* by sublethal doses of x rays. *Radiation Res.* 21, 413-22 (1964).

ODARTCHENKO, N. – See also COTTIER, H.; KEISER, G.; NIELSEN, N.O.

OJI, N. – See SHREEVE, W.W.

PAINTER, R.B., DREW, R.M., AND RASMUSSEN, R.E. Limitations in the use of carbon-labeled and tritium-labeled thymidine in cell culture studies. *Radiation Res.* 21, 355-66 (1964).

PAINTER, R.B. – See also DREW, R.M.

PAPAVASILIOU, P.S. – See COTZIAS, G.C.; PATTEN, B.M.

PATTEN, B.M., SAKAMOTO, A., VAN WOERT, M.H., PAPAVASILIOU, P.S., AND COTZIAS, G.C. Tremorine-induced tremor versus extrapyramidal disease. *Nature* 201, 929-30 (1964).

PAVELEC, M. – See TONNA, E.A.

PENTEL, L. AND TONNA, E.A. Improved strontium autoradiography of mineralized tissues with internal conversion and Auger electron emitting Sr^{85}. *Lab. Invest.* (in press).

PRICE, D.C., FORSYTH, E.M., COHN, S.H., AND CRONKITE, E.P. The study of menstrual and other blood loss and consequent iron deficiency by Fe^{59} whole-body counting. *Can. Med. Assoc. J.* 90, 51-4 (1964).

PRICE, D.C. – See also FISCHER, D.S.; SCHIFFER, L.M.

RAI, K.R. – See COTTIER, H.; CRONKITE, E.P.; JANSEN, C.R.; LIPPINCOTT, S.W.

RASMUSSEN, H. AND SCHWARTZ, I.L. Studies of the interaction between neurohypophyseal hormones and the amphibian urinary bladder. Chapter in *Oxytocin, Vasopressin* and *Their Analogues,* J. Rudinger, Editor, Pergamon, New York (in press).

RASMUSSEN, H. – See also SCHWARTZ, I.L.; PAINTER, R.B.

REILLY, P. – See HUGHES, W.L.

RIKLON, E. – See CONARD, R.A.

ROBERTSON, J.S. Diagnostic and therapeutic use of short-lived isotopes. (A) Presented at Symp. Utilization of Research Reactors, Atlanta, Nov. 1963.

ROBERTSON, J.S. Neutron dosimetry in intracranial irradiations. (A) Presented at Biomathematics Symp., Houston, May 1964.

ROBERTSON, J.S. AND COHN, S.H. Evaluation of plutonium exposures in man. *Health Phys.* 10, 373-89 (1964).

ROBERTSON, J.S. AND NIELL, A.M. Use of a digital computer in the development of a positron scanning procedure. In *Proc. 4th IBM Medical Symposium, Oct. 1962, Endicott, N.Y.,* pp. 77-103, International Business Machines Corp., White Plains, N.Y.

ROBERTSON, J.S. – See also ARCHAMBEAU, J.O.; BOND, V.P.; COHN, S.H.; FLIEDNER, T.M.; MALSKY, S.J.

ROSSI, H.H. – See BATEMAN, J.L.; SMITH, H.H. (Biology).

ROSWIT, B. – See MALSKY, S.J.

RUBINI, J.R., KELLER, S., AND CRONKITE, E.P. *In vitro* DNA labeling of bone marrow and leukemic blood leukocytes with tritiated thymidine. Submitted to *J. Lab. Clin. Med.*

SAKAMOTO, A. – See COTZIAS, G.C.; PATTEN, B.M.

SCHACKOW, E. – See DAHL, L.K.

SCHIFFER, L.M., MEYER, L.M., WHITE, D., AND CRONKITE, E.P. Effect of prior injection of vitamin B_{12} analogues upon plasma clearance of labeled cyanocobalamin. (A) Presented at Am. Soc. Hematol. Meeting, Washington, Dec. 1963.

SCHIFFER, L.M., PRICE, D.C., CUTTNER, J., COHN, S.H., AND CRONKITE, E.P. A note concerning the "100% value" in iron adsorption studies by whole-body counting. (N) *Blood* 23, 757-61 (1964).

SCHIFFER, L.M. – See also MEYER, L.M.

SCHMAELER, M. – See HANKES, L.V.

SCHULTZE, B. – See HUGHES, W.L.

SCHWARTZ, I.L., RASMUSSEN, H., LIVINGSTON, L.M., AND MARC-AURELE, J. Neurohypophyseal hormone-receptor interactions. Chapter in *Oxytocin, Vasopressin and Their Analogues,* J. Rudinger, Editor, Pergamon, New York (in press).

SCHWARTZ, I.L., RASMUSSEN, H., MARC-AURELE, J., AND CHRISTMAN, D. Molecular phenomena related to the mechanism of action of vasopressin on membrane permeability. In *Biochemical Aspects of Hormone Action,* pp. 66-94, A.B. Eisenstein, Editor, Little, Brown, Boston, 1964.

SCHWARTZ, I.L. – See also GHOSE, A.; RASMUSSEN, H.

SCHWARTZ, S. – See SHREEVE, W.W.

SHAH, V. – See HUGHES, W.L.

SHELLABARGER, C.J. – See BOND, V.P.

SHIGETA, Y. AND SHREEVE, W.W. Fatty acid synthesis from glucose-1-H^3 and glucose-1-C^{14} in obese-hyperglycemic mice. *Am. J. Physiol.* 206, 1085-90 (1964).

SHIGETA, Y. – See also GHOSE, A.; SHREEVE, W.W.

SHREEVE, W.W. AND DE MEUTTER, R.C. Pathways of carbohydrate formation in man. III. Distribution labeling of blood glucose by DL-lactate-2-C^{14} or pyruvate-2-C^{14} in diabetic and nondiabetic subjects. *J. Biol. Chem.* 239, 729-34 (1964).

SHREEVE, W.W., DE MEUTTER, R.C., AND SHIGETA, Y. Effects of diabetes, insulin, tolbutamide and glucose load in the degradation of C^{14}-labeled lactate and pyruvate. *Diabetes* (in press).

SHREEVE, W.W., SHIGETA, Y., OJI, N., AND SLAVINSKI, R. Transfer of tritium from glucose, lactate, isocitrate, and malate to fatty acids of obese mice *in vivo*. (A) *Federation Proc.* 23, 165 (1964).

SHREEVE, W.W., SHIGETA, Y., TASHJIAN, A., OJI, N., AND SCHWARTZ, S. Utilization of ^{14}C or ^{3}H-labeled glucose, pyruvate, and lactate in obesity and in early diabetes. (A) Presented at 5th Congr. Intern. Diabetes Federation, Toronto July 1964.

SHREEVE, W.W. – See also GHOSE, A.; SHIGETA, Y.

SINGER, S. – See COTTIER, H.

SIPE, C.R. – See COTTIER, H.; CRONKITE, E.P.

SLAVINSKI, R. – See SHREEVE, W.W.

STONER, R.D. AND TERRES, G. Enhanced antitoxin responses in irradiated mice elicited by complexes of tetanus toxoid and specific antibody. *J. Immunol.* 91, 761-70 (1963).

STONER, R.D. – See also COTTIER, H.; HALE, W.M.; HAMMERSTROM, R.A.; HANKES, L.V.; HESS, M.W.,
STRAUB, R.F. – See LIPPINCOTT, S.W.
SUTOW, W.W. – See CONARD, R.A.
SWEET, W.H. – See LIPPINCOTT, S.W.
TASHJIAN, A. – See SHREEVE, W.W.
TASSINARI, L. – See DAHL, L.K.
TERRES, G. – See STONER, R.D.
THOMAS, E.D. – See FLIEDNER, T.M.
TONNA, E.A. An autoradiographic evaluation of the aging cellular phase of mouse skeleton using tritiated glycine. *J. Gerontol.* **19**, 198-206 (1964).
TONNA, E.A. The connective tissue framework of the femur. *Anat. Record* **149**, 559-76 (1964).
TONNA, E.A. An evaluation of birefringence of skeletal tissues with metachromatic dyes. *J. Royal Microscop. Soc.* **83**, 307-15 (1964).
TONNA, E.A. Fracture callus formation in young and old mice followed with polarized light microscopy. *Anat. Record* (in press).
TONNA, E.A. On the distribution of reduced silver grains in autoradiograms of bone and cartilage following H^3-amino acid administration. *Lab. Invest.* (in press).
TONNA, E.A. The possibility of osteoclast aging investigated autoradiographically with tritiated histidine (H^3HIL). (A) *J. Gerontol.* (in press).
TONNA, E.A. AND ARONSON, R.B. Autoradiographic assessment of proteolytic enzyme action following H^3-amino acid administration. (A) Presented at 15th Ann. Histochem. Soc. Meeting, Chicago, April 1964.
TONNA, E.A. AND CRONKITE, E.P. The effects of extraperiosteal injections of the components of blood on periosteal cell proliferation. *J. Cell Biol.* (in press).
TONNA, E.A. AND CRONKITE, E.P. The periosteum: Autoradiographic studies on cellular proliferation and transformation utilizing tritiated thymidine. In *Clinical Orthopaedics and Related Research* **30**, pp. 218-33, Lippincott, Philadelphia, 1963.
TONNA, E.A. AND CRONKITE, E.P. A study of the persistence of the H^3-thymdine label in the femora of rats. *Lab. Invest.* **13**, 161-71 (1964).
TONNA, E.A., CRONKITE, E.P., AND PAVELEC, M. A serial autoradiographic analysis of H^3-glycine utilization and distribution in the femora of growing mice. *J. Histochem. Cytochem.* **11**, 720-33 (1963).
TONNA, E.A. AND JEE, W.S.S. Origin of osteoclasts from the fusion of phagocytes. (L) *Nature* **200**, 225-7 (1963).
TONNA, E.A. – See also HWANG, W.S.S.; PENTEL, L.; ROGERS, E.J. (Instr. & Health Physics).
TRETTER, P. – See ATKINS, H.L.
VAN SLYKE, D.D. AND CARSON, P.E. A simplified technique for determination of small amounts of calcium as oxalate. *Clin. Chem.* **10**, 352-65 (1964).
VAN SOESTBERGEN, A.A. The relationship between the effect of radiation and the logarithm of the oxygen concentration at a fixed value of the radiation dose. (A) Presented at Biophys. Soc. Meeting, Chicago, Feb. 1964.
VAN WOERT, M.H. – See COTZIAS, G.C.; PATTEN, B.M.
WAKISAKA, C. – See JACOBS, G.J.
WALD, N. – See JACOBS, G.J.
WHITE, D. – See SCHIFFER, L.M.
WILDERMUTH, O. – See ARCHAMBEAU, J.O.
YAMAMOTO, Y.L., FEINENDEGEN, L.E., AND BOND, V.P. Effects of radiation on the RNA metabolism of the central nervous system. *Radiation Res.* **21**, 36-45 (1964).

Nuclear Engineering Department

ADLER, G., BALLANTINE, D.S., DAVIS, T., AND RANGANATHAN, R. Radiolysis of solid solutions of acrylamide and propionamide. *J. Phys. Chem.* **68**, 2184-9 (1964).
ADLER, G. AND PETROPOULOS, J.H. ESR spectroscopy of irradiated acrylamide. (A) Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.
ADLER, G. AND REAMS, W. Polymerization in solid solutions of acrylamide in propionamide. *J. Polymer Sci. Pt. A: General Papers* **2**, 2617-21 (1964).
ADLER, G. – See also KENEALLY, E.
ANDERSEN, E. – See HELLENS, R.L.
ANDREA, C. – See GODEL, J.B.
ARONSON, A. – See LEVINE, M.M.
ARONSON, S. Thermodynamic properties of thorium carbides from measurements on solid EMF cells. *Intern. Symp. Compounds of Interest in Nuclear Reactor Technology (AIME, Boulder, Aug. 1964), Nucl. Met.* **10**, 247-54 (1964).
ARONSON, S. AND SADOFSKY, J. Thermodynamic properties of nonstoichiometric thorium monocarbide. Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.
ARONSON, S., SCHWEITZER, D.G., AND SINGER, R.M. Properties of irradiated and periodically annealed graphite. *Nucl. Sci. Eng.* **17**, 192-3 (1963).
ARONSON, S., SCHWEITZER, D.G., SINGER, R.M., AND DAVIS, J.G. Electrical properties of irradiated and periodically annealed graphite. (L) *J. Nucl. Mater.* **12**, 257-9 (1964).
ARONSON, S. – See also SALZANO, F.J.; SCHWEITZER, D.G.
AUERBACH, C. AND KISSEL, G. Determination of uranium at microgram levels by derivative polarography. *Talanta* **2**, 85-91 (1964).
AUERBACH, C. – See also FELDBERG, S.W.
AUERBACH, E.H. Inelastic-scattering calculations and spectroscopic assignments for nuclear levels. (A) *Bull. Am. Phys. Soc.* **9**, 166 (1964).
AUERBACH, E.H. AND BROWN, G.E. Proton-proton scattering in the GeV region. (L) *Phys. Letters* **6**, 95-7 (1963).
AUERBACH, E.H. AND MARGOLIS, B. Optical model for the pion-nucleon resonances. (L) *Phys. Rev. Letters* **11**, 286-7 (1963).
AUERBACH, E.H. AND PORTER, C.E. Neutron-nucleus optical model parameter effects on *s*-wave transmission coefficients. *Nucl. Phys.* (in press).
AUERBACH, E.H. – See also MOORE, S.O.; listing under Applied Mathematics.
AUSKERN, A. Noble gas diffusion in zirconium carbide. (A) Presented at AIME Meeting, New York, Feb. 1964.
AUSKERN, A. Observation on xenon evolution from uranium carbide. (A) Presented at Am. Ceram. Soc. Conv., Chicago, April 1964.
AUSKERN, A. Release of xenon from uranium carbide at low temperatures. *J. Am. Ceram. Soc.* **47**, 390-4 (1964).
BALLANTINE, D.S. AND GLINES, A. Graft copolymer studies on Mylar and nylon. In *Proc. 5th Japan Radioisotope*

Conf., Tokyo, May 1963, Vol. 2, pp. 72-7, Japan Atomic Industrial Forum, Inc., Tokyo, 1963.

BALLANTINE, D.S. – See also ADLER, G.

BECKER, W. – See SUSSKIND, H.

BELLER, M. – See SUSSKIND, H.

BLOCH, F.W., HAASBROEK, F.J., AND MACKENZIE, D.R. Metal containers for aqueous benzene-phenol dosimeters. *Nucleonics* 22, No. 3, 77 (1964).

CAGNETTA, J.P., GOELLNER, D., AND STEINBERG, M. Feasibility of a liquid phase chemonuclear ozone process. (A) *Trans. Am. Nucl. Soc.* 6, 315-16 (1963).

CARCIELLO, N. – See WEISS, J.

CASTLEMAN, A.W. JR., COTTRELL, W.B., BROWNING, W.E., PARKER, G.W., AND JUNKINS, R.L. U.S. experience on the release and transport of fission products within containment systems under simulated reactor accident conditions. *Proc. 3rd UN Intern. Conf. Peaceful Uses of Atomic Energy, Geneva, Sept. 1964* (in press).

CASTLEMAN, A.W. JR. AND SALZANO, F.J. Current studies of fission product behavior at BNL. In *8th AEC Air Cleaning Conf., Oak Ridge National Laboratory, Oct. 1963*, pp. 16-33, TID-7677, 1963.

CHANDRASEKHARAIAH, M.S. Dissociation energies of alkaline-earth oxides. (N) *J. Phys. Chem.* 68, 2020-1 (1964).

CHANDRASEKHARAIAH, M.S. Volatilities of refractory inorganic compounds. Chapter in *Characterization of High Temperature Vapors*, J.L. Margrave, Editor, Rice University, Houston (in press).

CHEN, J.C. A proposed mechanism and method of correlation for convective boiling heat transfer with liquid metals. *Proc. 3rd Ann. Conf. High-Temperature Liquid-Metal Heat Transfer Techniques, Oak Ridge National Laboratory, Sept. 1963* (in press).

CHEN, J.C. Simultaneous radiative and convective heat transfer in an absorbing, emitting, and scattering medium in slug flow between parallel plates. *A.I.Ch.E. J.* 10, 253-9 (1964).

CHEN, J.C. Some analyses related to convective boiling heat transfer. *Proc. Two-Phase Flow Meeting, Washington, April 1964* (in press).

CHERNICK, J. Characteristics of fast settled bed reactors. In *Proc. Conf. Breeding, Economics and Safety in Large Fast Power Reactors, Argonne National Laboratory, Oct. 1963*, pp. 587-93, ANL-6792, 1963.

CHERNICK, J. *The Nuclear Reactor Comes of Age, Brookhaven Lecture Series No. 31, Nov. 13, 1963.* BNL 838 (T-329).

CHERNICK, J. AND LEVINE, M.M. Developments in resonance absorption. *Proc. 3rd UN Intern Conf. Peaceful Uses of Atomic Energy, Geneva, Sept. 1964* (in press).

CHERNICK, J. – See also SRIKANTIAH, G.

CHOW, J.G.Y. AND MCRICKARD, S.B. Effects of neutron irradiation on the yield strength and grain size relationship in iron and iron-carbon alloys. (L) *Phil. Mag.* 8, 2097-9 (1963).

CHOW, J.G.Y. AND MCRICKARD, S.B. Low temperature embrittlement of iron, iron alloys and steels by neutron irradiations. (A) presented at ASTM Symp. Flow and Fracture Behavior of Metals and Alloys in Nuclear Environment, Chicago, June 1964.

CHOW, J.G.Y. AND MCRICKARD, S.B. Plastic deformation of neutron irradiated pure iron. (A) Presented at AIME Ann. Meeting, New York, Feb. 1964.

CHOW, J.G.Y. – See also MCRICKARD, S.B.

CLARKE, J.T. Surface area measurement of graphite using the γ-radiation of Kr^{85}. *J. Phys. Chem.* 68, 884-8 (1964).

COLLINS, C.H. – See SUSSKIND, H.; WEISS, J.

COLOMBO, P., KUKACKA, L.E., FONTANA, J., AND STEINBERG, M. Co^{60} gamma radiation-induced copolymerization of ethylene and carbon monoxide. (A) Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.

COLOMBO, P. AND STEINBERG, M. Copolymerization of ethylene induced by cobalt-60 gamma radiation. In *Industrial Uses of Large Radiation Sources (Proc. IAEA Conf., Salzburg, Austria, May 1963)*, Vol. 1, pp. 121-50, IAEA, Vienna, 1963.

CONKIE, W.R. An improved spherical harmonics method. *Nucl. Sci. Eng.* 18, 370-5 (1964).

CORNGOLD, N. Some transient phenomena in thermalization. I. Theory. *Nucl. Sci. Eng.* 19, 80-90 (1964).

CORNGOLD, N. AND MICHAEL, P. Some transient phenomena in thermalization. II. Implications for experiment. *Nucl. Sci. Eng.* 19, 91-4 (1964).

CORNGOLD, N. AND SHAPIRO, C.S. Time eigenvalues and degenerate kernels in thermalization. (A) *Trans. Am. Nucl. Soc.* 7, 52-3 (1964).

DAVIS, J.G. – See ARONSON, S.

DAVIS, T. – See ADLER, G.

DEVILLIERS, J. – See STARR, E.

DOMISH, R.F. AND HATCH, L.P. *Continuous Calcination of High Level Radioactive Wastes by Means of a Rotary Ball Kiln.* BNL 832 (T-326), Nov. 1963.

DWYER, J.E. – See FAJER, J.

DWYER, O.E. Bilateral heat transfer to annuli for slug and laminar flows. *Nucl. Sci. Eng.* 19, 48-57 (1964).

DWYER, O.E. Heat transfer to liquid metals flowing turbulently between parallel plates. Submitted to *Nucl. Sci. Eng.*

DWYER, O.E. On the transfer of heat to fluids flowing through pipes, annuli, and parallel plates. *Nucl. Sci. Eng.* 17, 336-44 (1963).

DWYER, O.E. AND LYON, R.N. Liquid-metal heat transfer. *Proc. 3rd UN Intern. Conf. Peaceful Uses of Atomic Energy, Geneva, Sept. 1964* (in press).

DWYER, O.E. AND TU, P.S. Bilateral heat transfer to liquid metals flowing turbulently through annuli. Submitted to *Nucl. Sci. Eng.*

DWYER, O.E. – See also KALISH, S.; MARESCA, M.W.; NIMMO, B.

EGAN, J.J. The standard molar free energy of formation of ThC_2 by electromotive force measurements. (N) *J. Phys. Chem.* 68, 978-9 (1964).

EGAN, J.J. – See also HEUS, R.J.; VAN NORMAN, J.D.

FAJER, J. AND DWYER, J.E. Reduction of selenium chelates. (A) Presented at Am. Chem. Soc. Meeting, Philadelphia, April 1964.

FARBER, G. – See STEINBERG, M.

FELDBERG, S.W. AND AUERBACH, C. A model for current reversal chronopotentiometry with second-order kinetic complications. *Anal. Chem.* 36, 505-9 (1964).

FELDER, R.M. – See HILL, F.B.

FELTMAN, A.V. – See COTTINGHAM, J.G. (Accelerator).

FLEITMAN, A.H. – See ROMANO, A.J.; WEEKS, J.R.

FONTANA, J. – See COLOMBO, P.

GALANTER, L. – See MANOWITZ, B.; MULLER, A.C.
GARD, J. – See KENEALLY, E.
GARRISON, J.D. A statistical analysis of neutron resonance parameters. *Ann. Phys. N.Y.* (in press).
GHATAK, A.K. The WKB method in the study of neutron thermalization in graphite. (A) *Trans. Am. Nucl. Sci.* **7**, 25 (1964).
GHATAK, A.K. AND HONECK, H.C. Approach to equilibrium of a neutron pulse in graphite. (A) *Trans. Am. Nucl. Soc.* 7, 46-7 (1964).
GHATAK, A.K. AND HONECK, H.C. On the feasibility of measuring higher time decay constants. *Nucl. Sci. Eng.* (in press).
GHATAK, A.K. AND KRIEGER, T.J. Neutron slowing down times and chemical binding in water. *Nucl. Sci. Eng.* (in press).
GLINES, A. – See BALLANTINE, D.S.
GODEL, J.B., HENDRIE, J.M., WEEKS, J.R., AND ANDREA, C. HFBR control rod blades and drive mechanisms. (A) Presented at IAEA Symp. Physics and Material Problems of Reactor Control Rods, Vienna, Nov. 1963.
GOELLNER, D. – See CAGNETTA, J.P.
GOLDBERG, M.D. Electron-atom scattering and nucleon-nucleus scattering – An analogy. In *Direct Interactions and Nuclear Reaction Mechanisms (Proc. Intern. Symp., Padua, Italy, Sept. 1962)*, pp. 164-6, Gordon & Breach, New York, 1963.
GOLDBERG, M.D. Neutron sources – Cross sections and angular distributions. In *Progress in Fast Neutron Physics (Proc. Intern. Conf., Houston, Feb. 1963)*, pp. 3-21, G.C. Phillips et al., Editors, University of Chicago Press, 1963.
GREENE, M.W. – See LIPPINCOTT, S.W. (Medical).
GROSSMAN, A.S. – See COTTINGHAM, J.G. (Accelerator).
GURINSKY, D.H. Contributions to TID-11295. In *Nuclear Fuels and Materials Development*, TID-11295, 3rd Ed., July 1964.
GURINSKY, D.H., WEEKS, J.R., KLAMUT, C.J., ROSENBLUM, L., AND DEVAN, J.H. Corrosion in liquid metal systems. *Proc. 3rd UN Intern. Conf. Peaceful Uses of Atomic Energy, Geneva, Sept. 1964* (in press).
GURINSKY, D.H. – See also KAMMERER, O.F.; ROMANO, A.J.; SCHWEITZER, D.G.
HAASBROEK, F.J. – See BLOCH, F.W.
HACHIYA, Y. – See LUTZ, H.R.
HALFORD, J. – See SADOFSKY, J.
HARPER, P.V. – See RICHARDS, P.I.
HATCH, L.P., WETH, G.G., AND TUTHILL, E.J. Ultimate disposal of high level radioactive wastes: Fixation in phosphate glass with emphasis on the continuous mode of plant operation. In *Treatment and Storage of High-Level Radioactive Wastes (Proc. IAEA Symp., Vienna, Oct. 1962)*, pp. 531-42, IAEA, Vienna, 1963.
HATCH, L.P. – See also DOMISH, R.F.
HELLENS, R.L. AND ANDERSEN, E. Some problems in the interpretation of exponential experiments. In *Exponential and Critical Experiments (Proc. IAEA Symp., Amsterdam, Sept. 1963)*, Vol. 2, pp. 21-41, IAEA, Vienna, 1964.
HELLENS, R.L. – See also PRICE, G.A.
HENDRIE, J.M. The Brookhaven High Flux Beam Research Reactor. *Proc. 3rd UN Intern. Conf. Peaceful Uses of Atomic Energy, Geneva, Sept. 1964* (in press).
HENDRIE, J.M. Final safety analysis report on the Brookhaven High Flux Beam Research Reactor, Vol. I and II. Informal Report BNL 7661.
HENDRIE, J.M. – See also GODEL, J.B.
HEUS, R.J. AND EGAN, J.J. Free energies of formation of some inorganic fluorides by solid state electromotive force measurements. Presented at Electrochem. Soc. Meeting, Washington, Oct. 1964.
HILL, F.B. Calculation of concentration response to intermittent irradiation. *A.I.Ch.E. J.* **10**, 166-73 (1964).
HILL, F.B. AND FELDER, R.M. An effect of mixing on the quantum yield of chain reactions in isothermal photoreactors. (A) Presented at Am. Inst. Chem. Engrs. Meeting, Boston, Dec. 1964.
HILLMAN, M. Construction of an extended nuclidic mass table. *Proc. Intern. Conf. Nuclidic Masses, Vienna, July 1963* (in press).
HILLMAN, M. *An Extended Table of Nuclidic Masses.* BNL 846 (T-333), March 1964.
HILLMAN, M. – See also WEISS, A.J.
HONECK, H.C. The calculation of the thermal utilization and disadvantage factor in uranium/water lattices. *Nucl. Sci. Eng.* **18**, 49-68 (1964).
HONECK, H.C. *A Review of the Methods for Computing Thermal Neutron Spectra.* BNL 821 (T-319), June 1963.
HONECK, H.C. – See also GHATAK, A.K.; STARR, E.; SUICH, J.E.
HORN, F.L. The volatile characteristics of several nitrosyl fluoride salts. In *Proc. Symp. Inorganic Fluorine Chemistry, Argonne National Laboratory, Sept. 1963*, p. 14.
HSU, C.-J. Analytical study of heat transfer to liquid metals in cross flow through rod bundles. *Intern. J. Heat Mass Transfer* **7**, 431-46 (1964).
HSU, C.-J. Heat transfer to liquid metals flowing past spheres and elliptical rod bundles. *Intern. J. Heat Mass Transfer* (in press).
HUSZAGH, D.W. – See KUHL, O.A.
KAHN, P.B. AND PORTER, C.E. Statistical fluctuations of energy levels: The unitary ensemble. *Nucl. Phys.* **48**, 385-407 (1963).
KALISH, S. AND DWYER, O.E. Heat transfer to NaK flowing in-line through a bundle of circular rods. Submitted to *J. Heat Transfer.*
KAMMERER, O.F., GURINSKY, D.H., AND SADOFSKY, J. Chemical and metallographic studies of Sputnik 4 fragments. (N) *J. Geophys. Res.* **68**, 5049-57 (1963).
KAMMERER, O.F. – See also SADOFSKY, J; STRONGIN, M. (Physics).
KATZ, H. AND ROTHBART, M. *Decontamination of Savannah River Waste Supernate by Ion Exchange.* BNL 853 (T-339), Feb. 1964.
KELSCH, J.J. Microscopy of radiation damage. (A) Presented at N.Y. Microscop. Soc. Meeting, New York, Feb. 1964.
KELSCH, J.J., GOLAND, A., AND PASKIN, A. Characteristics of thin metal films controlling fission track formation. (A) Presented at 22nd Ann. Meeting Electron Microscopy Soc., Detroit, Oct. 1964.
KELSCH, J.J., GOLAND, A.N., AND PASKIN, A. Factors controlling the production of fission-fragment tracks in thin metal films. *J. Phys. Chem. Solids* (in press).
KENEALLY, E., GARD, J., AND ADLER, G. The temperature dependence of birefringence in irradiated polyethylene. *J. Polymer Sci.* **2**, 1463-9 (1964).
KISSEL, G. – See AUERBACH, C.
KLAMUT, C.J. – See GURINSKY, D.H.; ROMANO, A.J.

KOUTS, H. The uses and potentialities of research reactors. *Proc. 3rd UN Intern. Conf. Peaceful Uses of Atomic Energy, Geneva, Sept. 1964* (in press).

KRIEGER, T.J. Generalized random-sign rules in *R*-matrix theory. (A) *Bull. Am. Phys. Soc.* **9**, 167 (1964).

KRIEGER, T.J. The independence hypothesis in the statistical theory of nuclear reactions. *Proc. Intern. Conf. Nuclear Physics, Paris, July 1964* (in press).

KRIEGER, T.J. A statistical theory of compound nucleus formation and decay. *Ann. Phys. N.Y.* (in press).

KRIEGER, T.J. – See also GHATAK, A.K.; PORTER, C.E.

KUHL, O.A., RIPPERGER, W., HUSZAGH, D.W., AND CRONKITE, E.P. Cobalt-60 irradiator for extracorporeal blood irradiation. *Nucleonics* **22**, No. 4, 79-83 (1964).

KUHL, O.A. – See also MANOWITZ, B.; OLTMAN, A.

KUKACKA, L.E. AND MANOWITZ, B. Economic estimates for gamma radiation processing. *Nucleonics* (in press).

KUKACKA, L.E., NUGENT, G., STONE, L., AND STEINBERG, M. Design of a high pressure gamma radiation loop. (A) *Trans. Am. Nucl. Soc.* **6**, 416 (1963).

KUKACKA, L.E. – See also COLOMBO, P.

LEVINE, M.M. AND ARONSON, A. Nuclear parameter studies of the fast settled bed reactor. In *Proc. Conf. Breeding, Economics and Safety in Large Fast Power Reactors, Argonne National Laboratory, Oct. 1963,* pp. 595-603, ANL-6792, 1963.

LEVINE, M.M. – See also CHERNICK, J.

LOEFFELHOLZ, M. – See STEINBERG, M.

LUTZ, H.R. AND HACHIYA, Y. ρ_{28} Measurements of tight water lattices with natural uranium foils. (A) Presented at Am. Nucl. Soc. Meeting, Salt Lake City, June 1963.

MACKENZIE, D.R. Krypton difluoride: Preparation and handling. *Science* **141**, 1171 (1963).

MACKENZIE, D.R. AND WISWALL, R.H. JR. The synthesis of xenon compounds in ionizing radiation. In *Noble Gas Compounds (Proc. Conf., Argonne National Laboratory, April 1963),* pp. 81-8, H.H. Hyman, Editor, University of Chicago Press, 1963.

MACKENZIE, D.R. – See also BLOCH, F.W.

MANOWITZ, B., KUHL, O.A., GALANTER, L., ARMEL, J., BLACK, K.M., KLAASSEN, W.J., PIGNATA, F.J., AND SLAVIN, J.W. *Study Report – Shipboard Cobalt-60 Radiopasteurizer for Marine Products.* BNL 808 (T-311), June 30, 1963.

MANOWITZ, B., KUHL, O.A., GALANTER, L., ARMEL, J., REIBACH, E.M., PIGNATA, F.J., AND HENDERSON, L.S. *Study Report – Cobalt-60 Bulk Grain Irradiator.* BNL 810 (T-312), June 30, 1963.

MANOWITZ, B., RASEMAN, C., STEINBERG, M., STOLLER, S., HOGERTON, J., AND GELLER, L. *A Chemonuclear Program for the USAEC.* BNL 804 (T-309), July 1963.

MANOWITZ, B., STEINBERG, M., SUTHERLAND, J.W., HARTECK, P., DONDES, S., AND CUSACK, J.H. The development of chemonuclear processes. *Proc. 3rd UN Intern. Conf. Peaceful Uses of Atomic Energy, Geneva, Sept. 1964* (in press).

MANOWITZ, B. – See also KUKACKA, L.E.; STEINBERG, M.

MARESCA, M.W. AND DWYER, O.E. Heat transfer to mercury flowing in-line through a bundle of circular rods. *J. Heat Transfer* **86**, 180-6 (1964).

MARGOLIS, B. – See AUERBACH, E.H.

MCRICKARD, S.B. Fast neutron dosimetry with fission monitors. In *Symp. Problems in Irradiation Capsule Experiments, Germantown, Md., Oct. 1963,* pp. 5.5.1-10, TID-7697, March 1964.

MCRICKARD, S.B. AND CHOW, J.G.Y. The effect of twinning on the yield stress of polycrystalline iron at low temperatures. (A) Presented at AIME Ann. Meeting, New York, Feb. 1964; CONF 524 5 (microneg.) NSA, Aug. 1964.

MCRICKARD, S.B. – See also CHOW, J.G.Y.

MICHAEL, P. Theoretical analysis of the exponential experiment in natural uranium. *Nucl. Sci. Eng.* **18**, 130-6 (1964).

MICHAEL, P. – See also CORNGOLD, N.

MOORE, S.O. AND AUERBACH, E.H. *Sigma Center Neutron Cross Section Evaluation Group: Optical Model Analysis of Inelastic Scattering of Neutrons by Heavy Nuclei.* BNL 818 (T-317), Aug. 1963.

MOORE, S.O. – See also AUERBACH, E.H. (Applied Mathematics).

MULLER, A.C., RIZZO, F.X., AND GALANTER, L. The "*n*" on "*p*" silicon solar-cell gamma-ray dose-rate meter. *Nucl. Sci. Eng.* **19**, 400-5 (1964).

MULLER, A.C. – See also RIZZO, F.X.

NESBET, R.K. Computation of matrix elements of integrable nuclear two-particle interaction operators. *J. Math. Phys.* **4**, 1262-71 (1963).

NIMMO, B. AND DWYER, O.E. Heat transfer to mercury flowing in-line through a rod bundle. (N) Submitted to *J. Heat Transfer.*

NUGENT, G. – See KUKACKA, L.E.

OLTMAN, A. AND KUHL, O.A. *Fabrication of BNL Standard Cobalt-60 Source.* BNL 848 (T-334), Feb. 1964.

PANCER, G.P. The settled bed reactor in-pile capsule. In *Symp. Problems in Irradiation Capsule Experiments, Germantown, Md., Oct. 1963,* pp. 2.14.1-11, TID-7697, March 1964.

PANCER, G.P. AND POWERS, R. Fuel studies under the settled bed reactor concept. In *Proc. Conf. Breeding, Economics and Safety in Large Fast Power Reactors, Argonne National Laboratory, Oct. 1963,* pp. 605-14, ANL-6792, 1963.

PASKIN, A. Effect of long-range interactions on order. *Phys. Rev.* **134**, A246-9 (1964).

PASKIN, A. The electronic contribution to the ordering energy. Submitted to *Alloying Behavior and Effects in Concentrated Solid Solutions,* T.B. Massalski, Editor, Gordon & Breach, New York.

PASKIN, A. Ordering and segregation in terms of the polar model of an alloy. *Phil. Mag.* **10**, 331-2 (1964).

PASKIN, A., STRONGIN, M., CRAIG, P.P., AND SCHWEITZER, D.G. The temperature dependence of the Ginzburg-Landau parameter. (A) Presented at 9th Intern. Conf. Low Temperature Physics, Columbus, Ohio, Sept. 1964.

PASKIN, A. – See also GOLAND, A.N. (Physics); KELSCH, J.J.; SCHWEITZER, D.G.; STRONGIN, M. (Physics).

PETROPOULOS, J.H. – See ADLER, G.

PHELPS, J.P. – See WEINSTOCK, E.V.

PORTER, C.E. Concepts in the statistical analysis of spectra. In *Symp. Statistical Properties of Atomic and Nuclear Spectra, Stony Brook, N.Y., May 1963,* Paper 1, P.B. Kahn, Editor, State University of New York at Stony Brook, 1963.

PORTER, C.E. Fluctuations of quantal spectra. In *Statistical Theories of Spectra: Fluctuations,* Academic, New York (in press).

PORTER, C.E. Statistical properties of compound states. Submitted to *Rev. Mod. Phys.*

PORTER, C.E. AND KRIEGER, T.J. Reduced width amplitude distributions and random sign rules in *R*-matrix theory. *J. Math. Phys.* **4**, 1272-9 (1963).

PORTER, C.E. – See also AUERBACH, E.H., KAHN, P.B.; ULLAH, N.

POWERS, R. – See PANCER, G.P.

PRICE, G.A. Experience at Brookhaven in the measurement of cell parameters. In *Exponential and Critical Experiments (Proc. IAEA Symp., Amsterdam, Sept. 1963)*, Vol. 2, pp. 3-18, IAEA, Vienna, 1964.

PRICE, G.A. A note on the measurement of the transport mean free path of thermal neutrons in graphite by a poison method. (L) *Nucl. Sci. Eng.* **18**, 410 (1964).

PRICE, G.A. AND HELLENS, R.L. Lattice studies in light water moderated systems. *Proc. 3rd UN Intern. Conf. Peaceful Uses of Atomic Energy, Geneva, Sept. 1964* (in press).

PRUZANSKY, J. – See STEINBERG, M.

RAND, A.C. – See STANG, L.G. JR.

RANGANATHAN, R. – See ADLER, G.

RASEMAN, C. – See MANOWITZ, B.

REAMS, W. – See ADLER, G.

RICHARDS, P.I. Application of short-lived radioisotopes to nuclear medicine. (A) Presented at New England Symp. Nuclear Medicine, Waterbury, Conn., April 1964.

RICHARDS, P.I. Hot cell operations at BNL. (A) *Trans. Ann. Nucl. Soc.* **6**, 471 (1963).

RICHARDS, P.I. AND GOUDSMIT, S.A. The order of electron shells in ionized atoms. *Proc. Natl. Acad. Sci. U.S.* **51**, 664-71 (1964).

RICHARDS, P.I. AND HARPER, P.V. A radiocolloid of Tc^{99m}. (A) Submitted to *J. Nucl. Med.*

RICHARDS, P.I. – See also STANG, L.G. JR.

RIPPERGER, W. – See KUHL, O.A.

RIZZO, F.X., MULLER, A.C., AND ZUCKER, M.S. Electrical discharge in gamma-irradiated lead shielding glass. (A) *Trans. Am. Nucl. Soc.* **6**, 467 (1963).

RIZZO, F.X. – See also MULLER, A.C.

ROMANO, A.J., KLAMUT, C.J., FLEITMAN, A.H., AND GURINSKY, D.H. Brookhaven National Laboratory liquid metal corrosion capsule questionnaire; Brookhaven National Laboratory liquid metal corrosion loop questionnaire. In *Proc. NASA-AEC Liquid Metal Corrosion Meeting, Cleveland, Sept. 1963*, pp. 179-86; pp. 209-12, NASA-SP-41, 1964.

ROMANO, A.J., KLAMUT, C.J. AND GURINSKY, D.H. *The Investigation of Container Materials for Bi and Pb Alloys, Part I. Thermal Convection Loops.* BNL 811 (T-313), July 1963.

ROMANO, A.J. – See also WEEKS, J.R.

ROTHBART, M. – See KATZ, H.

SADOFSKY, J., KAMMERER, O.F., AND HALFORD, J. Metallography of refractory metals subjected to liquid metal corrosion. Submitted to *Trans. AIME.*

SADOFSKY, J. – See also ARONSON, S.; KAMMERER, O.F.; SCHWEITZER, D.G.

SALZANO, F.J. The behavior of iodine in graphite. *Carbon* **2**, 73-81 (1964).

SALZANO, F.J. AND ARONSON, S. A kinetic study of the decomposition of cesium-graphite lamellar compounds. Presented at Am. Chem. Soc. Meeting, Chicago, Aug. 30 – Sept. 4, 1964.

SALZANO, F.J. AND ARONSON, S. Some experimental observations in the cesium-graphite system. (N) *J. Inorg. Nucl. Chem.* **26**, 1456-8 (1964).

SALZANO, F.J. – See also CASTLEMAN, A.W. JR.

SASTRE, C. AND WEINSTOCK, E.V. Delayed-neutron effects in pulsed-neutron measurements on multiplying assemblies. (L) Submitted to *Nucl. Sci. Eng.*

SCHWEITZER, D.G. Radiation damage in graphite. I. Consecutive and steady state reactions of interstitial complexes. Submitted to *Nucl. Sci. Eng.*

SCHWEITZER, D.G., CRAIG, P.P., STRONGIN, M., AND PASKIN, A. Field penetration in superconductors with surface layers. (A) Presented at 9th Intern. Conf. Low Temperature Physics, Columbus, Ohio, Sept. 1964.

SCHWEITZER, D.G. AND SINGER, R.M. Effect of irradiation temperature and annealing temperature on expansions and contractions in alternately irradiated and annealed graphite. (A) *Trans. Am. Nucl. Soc.* **6**, 383-4 (1963).

SCHWEITZER, D.G. AND SINGER, R.M. Interstitial reaction during neutron reirradiation in graphite. Submitted to *Nucl. Sci. Eng.*

SCHWEITZER, D.G. AND SINGER, R.M. Oxidation rates of alternately irradiated and annealed graphite. Submitted to *J. Nucl. Mater.*

SCHWEITZER, D.G. AND SINGER, R.M. Oxidation rates of alternately irradiated and annealed, periodically irradiated and annealed, and continuously irradiated graphites. Presented at Libby Cockcroft Graphite Chemistry Meeting, Richland, Wash., May 1964.

SCHWEITZER, D.G. AND SINGER, R.M. Removal of radiation damage from graphite by alternate reirradiations and low temperature anneals. *Nucl. Sci. Eng.* **19**, 385-9 (1964).

SCHWEITZER, D.G., SINGER, R.M., ARONSON, S., SADOFSKY, J., AND GURINSKY, D.H. Decomposition of defects by neutrons in reirradiated graphite. (L) *Nucl. Sci. Eng.* **18**, 406-8 (1964).

SCHWEITZER, D.G. – See also ARONSON, S.; PASKIN, A.; SINGER, R.M.; STRONGIN, M. (Physics).

SEHGAL, B.R. Resonance integral of thorium-232. (A) *Trans. Am. Nucl. Soc.* **6**, 41 (1963).

SELVIN, G. – See STANG, L.G. JR.

SHAPIRO, C.S. – See CORNGOLD, N.

SHOTKIN, L.M. A nonlinear analysis of a reactor with two temperature coefficients. *Nucl. Sci. Eng.* **18**, 271-9 (1964).

SHOTKIN, L.M. *Nonlinear Kinetics of a Two-Temperature Reactor.* BNL 815 (T-315), Aug. 1963.

SHOTKIN, L.M. Oscillations induced by two reactivity feedback coefficients. (A) *Trans. Am. Nucl. Soc.* **6**, 216 (1963).

SINGER, R.M. AND SCHWEITZER, D.G. Prevention of the radiation-induced enhancement of the oxidation rate of graphite. *Trans. Am. Nucl. Soc.* **7**, 122 (1964).

SINGER, R.M. – See also ARONSON, S.; SCHWEITZER, D.G.

SLATER, L.M. Extraction of sodium and cesium polyiodides into nitrobenzene. *Nucl. Sci. Eng.* **17**, 576-85 (1963).

SNYDER, W.T. A note on the prediction of wall shear stress distribution in the eccentric annulus. (N) *A.I.Ch.E. J.* **10**, 418-9 (1964).

SRIKANTIAH, G.S. AND CHERNICK, J. Plutonium fueled thermal reactors with high conversion ratios. *Nucl. Sci. Eng.* (in press).

STANG, L.G. JR. Activation analyses for medical research. The use of stable silver as a tracer. Informal Report BNL 7772.

STANG, L.G. JR. AND RICHARDS, P.I. Tailoring the isotope to the need. *Nucleonics* **22**, No. 1, 46-9 (1964).

STANG, L.G. JR., TUCKER, W.D., RAND, A.C., STRICKLAND, G., AND SELVIN, G. Remotely operated chemical processing equipment. Informal Report BNL 8064.

STARR, E., HONECK, H.C., AND DEVILLIERS, J. Determination of diffusion cooling in graphite by measurement of the average neutron velocity. *Nucl. Sci. Eng.* **18**, 230-5 (1964).

STEINBERG, M. Chemonuclear and radiation chemical process research at Brookhaven National Laboratory. (A) Presented at Radiochemical Processing Symp., Buffalo, May 1964.

STEINBERG, M. Deposition efficiency of fission-fragment energy. *Nucleonics* **21**, No. 8, 151-3 (1963).

STEINBERG, M. Radiation processing. Chapter in *1964 Yearbook of Science and Technology,* McGraw-Hill, New York (in press).

STEINBERG, M. AND FARBER, G. *Chemonuclear Fission Fragment Source and Fuel Element Development.* BNL 827 (T-322), Oct. 1963.

STEINBERG, M., LOEFFELHOLZ, M. AND PRUZANSKY, J. Fission fragment energy deposition efficiency for thin uranium-containing elements and the fixation of nitrogen. In *Industrial Uses of Large Radiation Sources (Proc. IAEA Conf., Salzburg, Austria, May 1963)* Vol. 2, pp. 87-119, IAEA, Vienna, 1963.

STEINBERG, M. AND MANOWITZ, B. The chemonuclear and radiation chemical process development program at BNL. *Proc. Radiation Processing Symp., Buffalo, May 1964* (in press).

STEINBERG, M. – See also CAGNETTA, J.P.; COLOMBO, P.; KUKACKA, L.E., MANOWITZ, B.

STONE, L. – See KUKACKA, L.E.

STRICKLAND, G. – See STANG, L.G. JR.

SUCHER, J. – See WEISS, J.

SUICH, J.E. AND HONECK, H.C. Transport theory calculations of temperature coefficients in heterogeneous reactor lattices. *Nucl. Sci. Eng.* **20**, 93-110 (1964).

SUSSKIND, H., WEISS, J., BECKER, W., BELLER, M., AND COLLINS, C.H. Organic reactor coolant studies. Informal Report BNL 7650.

SUTHERLAND, J.W. – See MANOWITZ, B.

TANG, Y.C., HERNDON, R.C., AND SCHMID, E.W. Hard-core Λ-Λ potential. (L) *Phys. Letters* **10**, 358-9 (1964).

TANG, Y.C., HERNDON, R.C. AND SCHMID, E.W. Upper and lower bound of the eigenvalue of a three-body system. *Phys. Rev.* **134**, B743-7 (1964).

TANG, Y.C., SCHMID, E. AND WILDERMUTH, K. The scattering of H^3 by alpha particles. *Phys. Rev.* **131**, 2631-41 (1963).

TASSAN, S. Fast fission factors in slightly enriched uranium, light water moderated slab lattices. (L) *Nucl. Sci. Eng.* **19**, 471-3 (1964).

TU, P.S. – See DWYER, O.E.

TUCKER, W.D. – See STANG, L.G. JR.

TUTHILL, E.J. – See HATCH, L.P.

ULLAH, N. *Evaluation of Atomic Level Widths.* BNL 794 (T-303), April 1963.

ULLAH, N. Reduced width amplitude distributions for the unitary ensemble. *J. Math. Phys.* **4**, 1279-82 (1963).

ULLAH, N. Theory of electron emission widths. *Phys. Rev.* **131**, 2094-8 (1963).

ULLAH, N. AND PORTER, C.E. Expectation value fluctuations in the unitary ensemble. *Phys. Rev.* **132**, 948-50 (1963).

ULLAH, N. AND PORTER, C.E. Invariance hypothesis and Hamiltonian matrix elements correlations. (L) *Phys. Letters* **6**, 301-2 (1963).

VAN NORMAN, J.D. Coulometric techniques in high-temperature systems. Article in *Encyclopedia of Electrochemistry,* pp. 303-5, C.A. Hampel, Editor, Reinhold, New York, 1964.

VAN NORMAN, J.D. Fused salt chronopotentiometry. *Ibid.,* pp. 630-2.

VAN NORMAN, J.D. Fused salt polarography. *Ibid.,* pp. 652-3.

VAN NORMAN, J.D. AND EGAN, J.J. The magnesium–magnesium chloride system. A chronopotentiometric study. *J. Phys. Chem.* **67**, 2460-2 (1963).

WEEKS, J.R. Corrosion in liquid-metal cooled reactors. In *Materials and Fuels for High Temperature Nuclear Energy Applications*, pp. 345-65, M.T. Simnad and L.R. Zumwalt, Editors, MIT Press, Cambridge, 1964.

WEEKS, J.R. Discussion of H. Nichols and W. Rostoker's paper, "Analogies between stress-corrosion cracking and embrittlement by liquid metals." (A) *Am. Soc. Metals Trans. Quart.* **56**, 959 (1963).

WEEKS, J.R., EPSTEIN, L.F., BONILLA, C.F., HOFFMAN, E.E., AND HORSLEY, G.W. Corrosion mechanisms: Panel presentation. In *Proc. NASA-AEC Liquid Metals Corrosion Meeting, Cleveland, Sept. 1963*, pp. 3-108, NASA-SP-41, 1964.

WEEKS, J.R. AND FLEITMAN, A.H. Solubility and corrosion in high temperature Hg. (A) Presented at Natl. Assoc. Corrosion Engrs. Corrosion Principles Symp. on Liquid Metals, Chicago, March 1964.

WEEKS, J.R. AND ROMANO, A.J. Solubility and corrosion rates of Fe in Bi-Ph alloys. (A) Presented at Natl. Assoc. Corrosion Engrs. Corrosion Principles Symp. on Liquid Metals, Chicago, March, 1964.

WEEKS, J.R. – See also GODEL, J.B.; GURINSKY, D.H.

WEINSTOCK, E.V. AND PHELPS, J.P. A simple detector for the measurement of room-scattered neutrons. (L) *Nucl. Sci. Eng.* **18**, 525-32 (1964).

WEINSTOCK, E.V. – See also SASTRE, C.

WEISS, A.J. AND HILLMAN, M. The magnesium-28–aluminum-28 system: An aluminum-28 generator. *Intern. J. Appl. Radiation Isotopes* **14**, 628-9 (1963).

WEISS, J., COLLINS, C.H., SUCHER, J., AND CARCIELLO, N. The radiolysis and pyrolysis of several polyaromatic compounds. *Ind. Eng. Chem.* **3**, 73-8 (1964).

WEISS, J. – See also SUSSKIND, H.

WETH, G.G. – See HATCH, L.P.

WILDERMUTH, K. – See TANG, Y.C.

WILLIAMS, M.M.R. The effect of chemical binding and thermal motion on a pulse of slowing-down neutrons. *Nucl. Sci. Eng.* **19**, 221-9 (1964).

WILLIAMS, M.M.R. The energy-dependent Milne problem with a simple scattering kernel. *Nucl. Sci. Eng.* **18**, 260-70 (1964).

WINDSOR, H. Bucklings and disadvantage factors of several water-moderated, 1.25%-enriched uranium metal slab lattices. (A) *Trans. Am. Nucl. Soc.* 6, 52-3 (1963).
WISWALL, R.H. JR. Energy storage for automotive use. Submitted to *Nucleonics.*
WISWALL, R.H. JR. – See also MACKENZIE, D.R.
ZUCKER, M.S. – See RIZZO, F.X.

Physics Department

ABRAHAMSON, A.A. Repulsive interaction potentials between rare-gas atoms. Heteronuclear two-center systems. *Phys. Rev.* 133, A990-1004 (1964).
AGULLO-LÓPEZ, F. AND LEVY, P.W. Effects of gamma-ray irradiation on the mechanical properties of NaCl single crystals. *Proc. Brit. Ceram. Soc.* 1, 183-96 (1964).
AITCHISON, I.J.R. Logarithmic singularities in processes with two final-state interactions. *Phys. Rev.* 133, B1257-66 (1964).
AITCHISON, I.J.R. AND KACSER, C. Complex propagators in perturbation theory. *Phys. Rev.* 133, B1239-57 (1964).
ALBURGER, D.E. Beta decay of Li^9. *Phys. Rev.* 132, 328-34 (1963).
ALBURGER, D.E., DONOVAN, P.F., AND WILKINSON, D.H. The beta decay of Li^8. *Phys. Rev.* 132, 334-42 (1963).
ALBURGER, D.E. AND PARKER, P.D. Search for double gamma-ray emission from the first excited states of O^{16} and C^{12}. *Phys. Rev.* 135, B294-300 (1964).
ALBURGER, D.E. AND WARBURTON, E.K. Magnetic pair spectrometer studies of electromagnetic transitions in C^{14} and N^{14}. *Phys. Rev.* 132, 790-6 (1963).
ALBURGER, D.E. – See also WARBURTON, E.K.
ALLEN, P.B. AND STERNHEIM, M.M. Corrections to π-e scattering: Numerical integrations. Informal Report BNL 7588.
ALPERIN, H.A. – See PICKART, S.J.; WILL, G.
ALPERT, S. – See COHEN, V.W.
ANDERSON, F. Illumination of 80-in. chamber. Informal Report BNL 7805.
ANDROULAKIS, J.G. Beam window stress analysis. Informal Report BNL 8148
ANDROULAKIS, J.G. Dynamics of a piston expansion bubble chamber. Informal Report BNL 8147.
ANDROULAKIS, J.G. Preliminary piston design, 80-in. bubble chamber. Informal Report BNL 8149.
ANDROULAKIS, J.G. Preliminary proposed neck design volume and weight calculation, 80-in. bubble chamber. Informal Report. BNL 8156.
ANDROULAKIS, J.G. Some considerations on the configuration and stability of the H_2 temperature control loops of the 80-in. bubble chamber. Informal Report BNL 7497.
ANDROULAKIS, J.G. Vacuum chamber stress analysis. Informal Report BNL 8150.
ARNDT, R.A. Radiation effects in iron-carbon alloys. (A) Presented at AIME Meeting, New York, Feb. 1964.
ARNDT, R.A. AND DAMASK, A.C. Kinetics of carbon precipitation in irradiated iron. III. Calorimetry. *Acta Met.* 12, 341-5 (1964).
ARNDT, R.A. – See also DAMASK, A.C.; GONZALO, J.A.
AYER, F. – See BARGE, D.A. (Accelerator); CHU, W.T. (Accelerator); PICKUP, E.
BACHMAN, A.H. – See BALTAY, C.; BARNES, V.E.; FERBEL, T.
BACON, T.C., HOPKINS, H.W.K., ROBINSON, D.K., SALANT, E.O., ENGLER, A., FISK, H.E., MELTZER, C.M., AND WESTGARD, J.B. Observation of the reaction $\bar{p}+d\rightarrow\Lambda+\Sigma^-+\bar{\Xi}^+$. *Phys. Rev.* 134, B1339-40 (1964).
BAKER, C.P. – See DONOVAN, P.F. (Chemistry); LIPPINCOTT, S.W. (Medical).
BAKER, W.F. A spark chamber film reading system. In *Proc. Conf. Programming for HPD and Other Flying Spot Devices, Collège de France, Paris, Aug. 1963*, CERN 63-34, pp. 171-83, CERN, Geneva, 1963.
BAKER, W.F. – See also JENKINS, E.W.; RILEY, K.F.
BALÁZS, L.A.P. Low momentum transfer pion-pion scattering. *Phys. Rev.* 132, 867-73 (1963); Errata, 134, No. 7AB, AB1 (1964).
BALTAY, C., FERBEL, T., SANDWEISS, J., TAFT, H.D., CULWICK, B.B., FOWLER, W.B., GAILLOUD, M., KOPP, J.K., LOUTTIT, R.I., MORRIS, T.W., SANFORD, J.R. SHUTT, R.P., STONEHILL, D.L., STUMP, R., THORNDIKE, A.M., WEBSTER, M.S., WILLIS, W.J., BACHMAN, A.H., BAUMEL, P., AND LEA, R.M. Interactions of high energy antiprotons in hydrogen. *Proc. Stanford Nucleon Structure Meeting, New Haven, June 1963* (in press).
BALTAY, C., SANDWEISS, J., TAFT, H.D., CULWICK, B.B., FOWLER, W.B., KOPP, J.K., LOUTTIT, R.I., SANFORD, J.R., SHUTT, R.P., STONEHILL, D.L., STUMP, R., THORNDIKE, A.M., AND WEBSTER, M.W. Observation of the production of a $\bar{\Xi}^0$ particle. (L) *Phys. Rev. Letters* 11, 165-7 (1963).
BALTAY, C., SANDWEISS, J., TAFT, H.D., CULWICK, B.B., FOWLER, W.B., KOPP, J.K., LOUTTIT, R.I., SANFORD, J.R., SHUTT, R.P., STONEHILL, D.L., THORNDIKE, A.M., AND WEBSTER, M.S. Investigations of $\Upsilon^*$and $\bar{\Upsilon}^*$ production in reactions of the type $\bar{p}+p\rightarrow\Upsilon+\bar{\Upsilon}+\pi$. (L) *Phys. Rev. Letters* 11, 346-9 (1963).
BAMBERGER, J.A. Cool-down refrigeration requirements for 80-in. bubble chamber. Informal Report BNL 7496.
BAMBERGER, J.A., BROWN, D.P., AND JENSEN, J.E. General description of the 80-in. bubble chamber refrigeration system. Informal Report BNL 7492.
BAMBERGER, J.A., BROWN, D.P., AND JENSEN, J.E. Hydrogen refrigerator design capacity for 80-in. chamber. Informal Report BNL 7487.
BARDIN, B.M. – See RICKEY, M.E.
BARNES, V.E., CONNOLLY, P.L., CRENNELL, D.J., CULWICK, B.B., DELANEY, W.C., FOWLER, W.B., HAGERTY, P.E., HART, E.L., HORWITZ, N., HOUGH, P.V.C., JENSEN, J.E., KOPP, J.K., LAI, K.W., LEITNER, J., LLOYD, J.L., LONDON, G.W., MORRIS, T.W., OREN, Y., PALMER, R.B., PRODELL, A.G., RADOJICIC, D., RAHM, D.C., RICHARDSON, C.R., SAMIOS, N.P., SANFORD, J.R., SHUTT, R.P., SMITH, J.R., STONEHILL, D.L., STRAND, R.C., THORNDIKE, A.M., WEBSTER, M.S., WILLIS, W.J., AND YAMAMOTO, S.S. Observation of a hyperon with strangeness minus three. (L) *Phys. Rev. Letters* 12, 204-6 (1964).
BARNES, V.E., CONNOLLY, P.L., CRENNELL, D.J., CULWICK, B.B., FOWLER, W.B., HART, E.L., HORWITZ, N., HOUGH, P.V.C., KOPP, J.K., LAI, K.W., LEITNER, J., LLOYD, J.L., LONDON, G.W., MORRIS, T.W., OREN, Y., PALMER, R.B., PRODELL, A.G., RADOJICIC, D., RAHM, D.C., RICHARDSON, C.R., SAMIOS, N.P., SMITH,

J.R., STRAND, R.C., AND THORNDIKE, A.M. Mass of the Ω^- hyperon and cross section for its production by 5-BeV/c K^- mesons. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

BARNES, V.E., CULWICK, B.B., LLOYD, J.L., PALMER, R.B., RADOJICIC, D., RICHARDSON, C.R., SAMIOS, N.P., SMITH, J.R., GOLDBERG, M., GOZ, B., GUNDZIK, M., HORWITZ, N., LEITNER, J., PRIMER, M., AND WOLFE, R. Production of Ξ hyperons by 5-BeV/c K^- mesons. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

BARNES, V.E., FOWLER, W.B., LAI, K.W., RADOJICIC, D., RAHM, D.C., AND WEBSTER, M.S. A study of $\pi^- + p \rightarrow K_1^0 + n$ reaction at 6 BeV/c. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

BARNES, V.E., FOWLER, W.B., LAI, K.W., RADOJICIC, D., RAHM, D.C., WEBSTER, M.S., BACHMAN, A.H., BAUMEL, P., AND LEA, R.M. Multipion production by negative pions in hydrogen at 6 BeV/c. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

BARNES, V.E., LAI, K.W., ANNINOS, P., GRAY, L., HAGERTY, P., HARTH, E., KALOGEROPOULOS, T., ZENONE, S., DORE, V., MONETI, G., AND VALENTE, V. Pion and kaon production in antiproton neutron annihilations at rest. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

BARNES, V.E., LAI, K.W., ANNINOS, P., GRAY, L., HAGERTY, P., HARTH, E., KALOGEROPOULOS, T., ZENONE, S., DORE, V., MONETI, G., AND VALENTE, V. Production of ϕ and ω in antiproton-neutron annihilations at rest. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

BARNES, V.E., LAI, K., ANNINOS, P., GRAY, L., HAGERTY, P., HARTH, E., KALOGEROPOULOS, T., ZENONE, S., DORE, V., MONETI, G., AND VALENTE, V. Production of ω and ϕ mesons in $\bar{p}$-n annihilations at rest. (A) *Bull. Am. Phys. Soc.* 9, 459 (1964).

BARTRAM, R.H. – See GAMBLE, F.T.

BECKER, J.A., MITCHELL, G.E. AND DONOVAN, P.F. Radiative decay of some low lying states of Mg^{27}. *Phys. Rev.* 135, B587-90 (1964).

BECKER, J.A. AND WARBURTON, E.K. Lifetimes of the N^{14} 5.83-MeV and 6.44-MeV levels. *Phys. Rev.* 134, B349-52 (1964).

BECKER, J.A. AND WILKINSON, D.H. Electric quadrupole transitions near $A = 16$: The lifetimes of the first excited states of O^{17} and F^{17}. *Phys. Rev.* 134, B1200-4 (1964).

BÉG, M.A.B. On the peratization theory of Feinberg and Pais. *Ann. Phys. N.Y.* 27, 183-92 (1964).

BERNABEI, A. *The Effects of Crystalline Binding on the Doppler Broadening of a Neutron Resonance.* BNL 860 (T-344), June 1964.

BERTANZA, L. – See YAMAMOTO, S.S.

BETHE, H.A. – See READ, A.L.

BLINOWSKI, K. – See PASSELL, L.

BLUME, M. Polarization effects in slow neutron scattering. II. Spin-orbit scattering and interference effects. *Phys. Rev.* 133, A1366-9 (1964).

BLUME, M. Two lectures on the magnetic scattering of neutrons. *Proc. 10th Yugoslav Summer School in Physics, Hercegnovi, Sept. 1963* (in press).

BLUME, M., FREEMAN, A.J., AND WATSON, R.E. Theory of spin-orbit coupling in atoms. III. *Phys. Rev.* 134, A320-7 (1964).

BLUME, M. AND WATSON, R.E. Spin-spin interaction in paramagnetic ions. (A) *Bull. Am. Phys. Soc.* 9, 402 (1964).

BOUTIN, H., FRAZER, B.C., AND JONA, F. Structural effects of ionizing radiation in ferroelectric Rochelle salt. *J. Phys. Chem. Solids* 24, 1341-7 (1963).

BOUTIN, H., SAFFORD, G.J., AND BRAJOVIC, V. Study of low frequency molecular motions in HF, KHF_2, KH_2F_3 and NaH_2F_3. *J. Chem. Phys.* 39, 3135-40 (1963).

BOUTIN, H., SAFFORD, G.J., AND DANNER, H.R. Low frequency motions of H_2O molecules in crystals. *J. Chem. Phys.* 40, 2670-9 (1964).

BOUTIN, H. – See also DANNER, H.R.; SAFFORD, G.J.; VAN DEN HENDE, J.H.

BRAJOVIC, V. – See BOUTIN, H.

BREDIN, D.J. Scattering and polarization of neutrons for Al, Si, Fe, and Co at 2 MeV. *Phys. Rev.* 135, B412-16 (1964).

BREDIN, D.J., OLNESS, J.W., AND WARBURTON, E.K. Gamma-ray transitions in B^{10} and Be^{10}. (A) *Bull. Am. Phys. Soc.* 9, 407 (1964).

BREDIN, D.J. – See also WARBURTON, E.K.

BROWN, D.P. Chamber vent line size. Informal Report BNL 8157.

BROWN, D.P. Estimate of steady-state static refrigerator requirements for 80-in. bubble chamber. Informal Report BNL 8158.

BROWN, D.P. Evaluation of multilayer insulation. Informal Report BNL 7494.

BROWN, D.P. Specification for 125-psi air purification and dehydration system. Informal Report BNL 8161.

BROWN, D.P. Specification for 250-psi hydrogen room temperature purification and dehydration system. Informal Report BNL 8159.

BROWN, D.P. Specifications for 3000-psi nitrogen room temperature purification and dehydration system. Informal Report BNL 8160.

BROWN, D.P. – See also BAMBERGER, J.A.

BROWN, P.J. – See WILL, G.

BRUN, T. – See PASSELL, L.

BRUNHART, G. – See SHORE, F.J.

BUBBLE CHAMBER GROUP. A proposed 25,000-liter liquid hydrogen bubble chamber. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

BURD, D. AND CONNOLLY, P.L. Computer association of tracks in different views. In *Proc. Conf. Programming for HPD and Other Flying Spot Devices, Collège de France, Paris, Aug. 1963,* CERN 63-34, pp. 215-21, CERN, Geneva, 1963.

BURD, D. AND WEBRE, N. Controlled filter and smoothing. In *Proc. Conf. Programming for HPD and Other Flying Spot Devices, Collège de France, Paris, Aug. 1963*, CERN 63-34, pp. 77-83, CERN, Geneva, 1963.

BURNSTEIN, R.A., DAY, T.B., HERZ, A.J., KEIHOE, B., ZORN, B.S., SEEMAN, N., SNOW, G.A., COURANT, H., FILTHUTH, H., FRANZINI, P., GLASSER, R.G., MINGUZZI-RANZI, A., SEGAR, A., AND WILLIS, W. Charged sigma hyperon leptonic decays. (L) Submitted to *Phys. Rev. Letters.*

BURNSTEIN, R.A. – See also COURANT, H.

STEIN, R.A., DAY, T.B., HERZ, F., KEHOE, B., ZORN, B.S., SEEMAN, N., AND SNOW, G.A. Leptonic decays of Σ-hyperons. (A) Presented at Intern. Conf. Elementary Particles, Sienna, Italy, Oct. 1963.

COURANT, H., FILTHUTH, H., FRANZINI, P., MINGUZZI-RANZI, A., SEGAR, A., ENGELMANN, R., HEPP, V., KLUGE, E., BURNSTEIN, R.A., DAY, T.B., GLASSER, R.G. HERZ, A.J., KEHOE, B., ZORN, B.S., SEEMAN, N., SNOW, G.A., AND WILLIS, W.J. *Leptonic Decays of Charged Sigma Hyperons and the* $\Delta S = \Delta Q$ *Selection Rule.* University of Maryland Tech. Rept. **394**, Aug. 1964.

COURANT, H. – See also BURNSTEIN, R.A.

COX, D.E., SHIRANE, G., AND TAKEI, W.J. Magnetic structures in the MnSb-CrSb and CrTe-CrSb systems. *Proc. Intern. Conf. Magnetism, Nottingham, England, Sept. 1964* (in press).

COX, D.E. – See also KURIYAMA, M.; SHIRANE, G.; WILL, G.

CRAIG, P.P. Nonvanishing normal fluid divergence and the influence of second viscosity upon the steady-state flow of superfluid helium II. (A) *Bull. Am. Phys. Soc.* **9**, 437 (1964).

CRAIG, P.P. Observations on Mössbauer resonance in a liquid. (A) Presented at 3rd Intern. Conf. Mössbauer Effect, Ithaca, N.Y., Sept. 1963.

CRAIG, P.P., KISTNER, O.C., MOZER, B., AND SEGNAN, R. Recoil free resonance using delayed coincidence techniques. (A) Presented at 3rd Intern. Conf. Mössbauer Effect, Ithaca, N.Y., Sept. 1963.

CRAIG, P.P. AND SUTIN, N. The Mössbauer effect in liquids: Influence of diffusion broadening. (L) *Phys. Rev. Letters* **11**, 460-2 (1963).

CRAIG, P.P. – See also PASKIN, A. (Nuclear Engineering); SCHWEITZER, D.G. (Nuclear Engineering); SEGNAN, R.; STRONGIN, M.

CRASEMANN, B., EMERY, G.T., KANE, W.R., AND PERLMAN, M.L. Properties of radioactive Re^{189}. *Phys. Rev.* **132**, 1681-90 (1963).

CRENNELL, D.J. – See BARNES, V.E.

CULWICK, B.B. 80-in. Bubble chamber magnet coils. Informal Report BNL 7481.

CULWICK, B.B. 80-in. Chamber expansion system electronic control notes. Informal Report BNL 8092.

CULWICK, B.B. Magnet coils – Detailed conductor design. Informal Report BNL 7491.

CULWICK, B.B. Magnetic force on the piston of the 80-in. bubble chamber. Informal Report BNL 8093.

CULWICK, B.B. Some parameters of the 80-in. chamber magnet coils. Informal Report BNL 7488.

CULWICK, B.B. Suggested programme for testing the AGS RBD. Informal Report BNL 8140.

CULWICK, B.B., HOSIE, J.W., AND THORNDIKE, A.M. Two-dimensional magnet models for the 80-in. liquid hydrogen bubble chamber. Informal Report BNL 8099.

CULWICK, B.B. – See also BALTAY, C.; BARNES, V.E.

DAMASK, A.C. Effects of radiation in alloys. (A) Presented at AIME Meeting, New York, Feb. 1964.

DAMASK, A.C. AND ARNDT, R.A. The effect of iron vacancies on the diffusion of interstitial carbon in Fe-C alloys. *Proc. 5th Intern. Symp. Reactivity of Solids, Munich, Aug. 1964* (in press).

DAMASK, A.C. AND DIENES, G.J. Effect of mobile vacancy-impurity complexes on vacancy annealing kinetics. *Acta Met.* **12**, 797-801 (1964).

DAMASK, A.C., JOHNSON, R.A., AND DIENES, G.J. Interstitial impurity migration in α-iron and vanadium. (A) *Bull. Am. Phys. Soc.* **9**, 295 (1964).

DAMASK, A.C. – See also ARNDT, R.A.; DIENES, G.J.; FUJITA, F.E.; JOHNSON, R.A.; LARSEN, R.E.; WAGENBLAST, H.

DANNER, H.R., SAFFORD, G.J., BOUTIN, H., AND BERGER, M. Study of low-frequency motions in polyethylene and the paraffin hydrocarbons by neutron inelastic scattering. *J. Chem. Phys.* **40**, 1417-25 (1964).

DANNER, H.R. – See also BOUTIN, H.; CHOI, C.S.; SAFFORD, G.J.

DAY, T.B. – See BURNSTEIN, R.A.; COURANT, H.

DE CELLES, P.C. – See CHAN, H.M.

DELANEY, W.C. – See BARNES, V.E.

DIDDENS, A.N., JENKINS, E.W., KYCIA, T.F., AND RILEY, K.F. The K^--p total cross section between 2.7 and 5.2 BeV/c. *Phys. Rev.* **132**, 2721-3 (1963).

DIENER, J.J. Calculated speed of a longitudinal wave in the vacuum chamber bellows. Informal Report BNL 8135.

DIENER, J.J. Cryogenic test on indium-coated copper seal. Informal Report BNL 8134.

DIENER, J.J. 80-in. Liquid H_2 bubble chamber: Expansion system. Informal Report BNL 8137.

DIENER, J.J. High molecular weight (2,000,000 M.W.) polyethylene. Informal Report BNL 8133.

DIENER, J.J. Improvements in future honeycomb pistons. Informal Report BNL 8139.

DIENER, J.J. Inspection of the piston positioner. Informal Report BNL 8138.

DIENER, J.J. AND GOODZEIT, C.L. Expansion system test facility. Informal Report BNL 8136.

DIENES, G.J. Point defects in metals. *Proc. Sci. Seminar Theoretical Metallurgy, Denver, July 22 – Aug. 2, 1963* (in press).

DIENES, G.J. AND DAMASK, A.C. The role of point defects in solid state reactions. *Proc. 5th Intern. Symp. Reactivity of Solids, Munich, Aug. 1964* (in press).

DIENES, G.J. – See also DAMASK, A.C.; HATCHER, R.D.; JOHNSON, R.A.; LARSEN, R.E.; ROSENBLATT, D.B.

DORE, V. – See BARNES, V.E.

EDELSTEIN, R.M. – See TURKOT, F.

EHLERS, V.J. – See CHAN, Y.W.

EMERY, G.T. – See BERGSTROM, I. (Chemistry); CRASEMANN, B.; IKEGAMI, H.; SCHWARZSCHILD, A.

EMERY, V.J. Spin-diffusion in gases at low temperatures. *Phys. Rev.* **133**, A661-4 (1964).

ENGELMANN, R. – See COURANT, H.

ENGLERT-CHWOLES, A. – See ERGINSOY, C.

ERGINSOY, C. Anomalous penetration of rare gas atoms in lattice channels. (L) *Phys. Rev. Letters* **12**, 366-7 (1964).

ERGINSOY, C. Collisional excitation and ionization of rare gas atoms in lattice channels. (A) *Bull. Am. Phys. Soc.* **9**, 397 (1964).

ERGINSOY, C. Dynamics of atomic displacement processes. II. Influence of crystal lattice on cascade. *Proc. Intern. Summer School Solid State Physics, Mol, Belgium, Aug. 1963* (in press).

ERGINSOY, C. Limitations of the elastic model of atomic collisions in solids. (A) Presented at Symp. Atomic Collision Cascades, Harwell, England, July 1964.

ERGINSOY, C. Low-energy radiation damage processes in a body-centered cubic lattice. *Am. Soc. Testing Mater. Spec. Tech. Publ.* **359**, 79-97 (1964).

ERGINSOY, C., VINEYARD, G.H., AND ENGLERT-CHWOLES, A. Dynamics of radiation damage in a body-centered cubic lattice. *Phys. Rev.* **133**, A595-606 (1964).

ERGINSOY, C. – See also GIBSON, W.M. (Chemistry); SHIMIZU, A.

FABIAN, B.N., PLACE, R.L., RILEY, W.A., SIMS, W.H., AND KENNEY, V.P. Density of particle tracks in the hydrogen bubble chamber. *Rev. Sci. Instr.* **34**, 484-95 (1963).

FERBEL, T., SANDWEISS, J., TAFT, H.D., GAILLOUD, M., MORRIS, T.W., WILLIS, W.J., BACHMAN, A., BAUMEL, P., AND LEA, R.M. Dipion mass spectra in antiproton-proton annihilations at 3 to 4 BeV/*c*. Informal Report BNL 7969.

FERBEL, T., SANDWEISS, J., TAFT, H.D., GAILLOUD, M., MORRIS, T.W., WILLIS, W.J., BACHMAN, A., BAUMEL, P., AND LEA, R.M. Multipion annihilation of antiprotons in hydrogen at 3.4 BeV/*c*. (A) *Bull. Am. Phys. Soc.* **9**, 22 (1964).

FERBEL, T. – See also BALTAY, C.

FILTHUTH, H. – See BURNSTEIN, R.A.; COURANT, H.

FISK, H.E. – See BACON, T.C.

FLINN, P.A. – See KURIYAMA, M.

FOLEY, K.J., GILMORE, R.S., LINDENBAUM, S.J., LOVE, W.A., OZAKI, S., WILLEN, E.H., YAMADA, R., AND YUAN, L.C.L. Digitized sonic spark chamber for operation with counter hodoscope, data handling system and on-line computer. In *Proc. Informal Meeting Film-less Spark Chamber Techniques and Associated Computer Use, Geneva, March 1964*, CERN 64-30, pp. 237-44, CERN, Geneva, 1964.

FOLEY, K.J., HIGINBOTHAM, W.A., LINDENBAUM, S.J., LOVE, W.A., OZAKI, S., POTTER, D. AND YUAN, L.C.L. A high capacity digital data handling system for use with counter hodoscopes and digitized spark chambers in on-line computer AGS experiments. In *Proc. Informal Meeting Film-less Spark Chamber Techniques and Associated Computer Use, Geneva, March 1964*, CERN 64-30, pp. 21-9, CERN, Geneva, 1964; BNL 852 (T-338), March 1964.

FOLEY, K.J., LINDENBAUM, S.J., LOVE, W.A., OZAKI, S., RUSSELL, J.J., AND YUAN, L.C.L. Antiproton and kaon elastic scattering at high energies. (L) *Phys. Rev. Letters* **11**, 503-6 (1963).

FOLEY, K.J., LINDENBAUM, S.J., LOVE, W.A., OZAKI, S., RUSSELL, J.J., AND YUAN, L.C.L. A counter hodoscope digital data handling and on-line computer system used in high energy scattering experiments. In *Proc. Informal Meeting Film-less Spark Chamber Techniques and Associated Computer Use, Geneva, March 1964*, CERN 64-30, pp. 11-20, CERN, Geneva, 1964; *Nuclear Instr. Methods* 27, 82 (1964).

FOLEY, K.J., LINDENBAUM, S.J., LOVE, W.A., OZAKI, S., RUSSELL, J.J., AND YUAN, L.C.L. Small-angle elastic scattering of protons and pions, 7-20 BeV/*c*. (L) *Phys. Rev. Letters* **11**, 425-9 (1963).

FOWLER, E., KRAYBILL, H.L., LEA, R.M., SANFORD, J.R., SANDWEISS, J., AND THORNDIKE, A.M. Location of 3-BeV proton beam for BNL 20-in. bubble chamber. II. Informal Report BNL 8095.

FOWLER, W.B. – See BALTAY, C.; BARNES, V.E.

FRANZINI, P. AND LEE-FRANZINI, J. Some remarks on the lifetimes of the massive triplets. (L) *Phys. Rev. Letters* **12**, 602-3 (1964).

FRANZINI, P. – See also BURNSTEIN, R.A.; COURANT, H.

FRAZER, B.C., ALMODOVAR, I., BIELEN, H.J., AND KAY, M.I. Neutron diffraction studies at the Puerto Rico Nuclear Center. *J. Phys. Radium* (in press).

FRAZER, B.C., KAY, M.I., AND ALMODOVAR, I. A neutron diffraction refinement of $CaWO_4$. *J. Chem. Phys.* **40**, 504-6 (1964).

FRAZER, B.C. – See also BOUTIN, H.; WILL, G.

FRIEDES, J.L. Multiple scattering corrections to partial neutron cross section measurements. Informal Report BNL 8028.

FRIEDES, J.L. AND CHRIEN, R.E. Design of He^3-filled fast proportional counters. *Rev. Sci. Instr.* **35**, 469-72 (1964).

FRIEDES, J.L., CHRIEN, R.E., MUGHABGHAB, S., MYERS, V.W., SUTTER, R.J., AND PALEVSKY, H. Total neutron-proton cross sections in the 2- to 3-BeV region (A) *Bull. Am. Phys. Soc.* **9**, 94 (1964).

FRIEDES, J.L. AND COLE, I.W. Multiple scattering corrections to self-indication ratios. (A) *Bull. Am. Phys. Soc.* **9**, 432 (1964).

FRIEDES, J.L. – See also MUETHER, H.R.; PALEVSKY, H.

FUJII, T. – See TURKOT, F.

FUJITA, F.E. AND DAMASK, A.C. Kinetics of carbon precipitation in irradiated iron. II. Electrical resistivity measurements. *Acta Met.* **12**, 331-9 (1964).

FUJITA, F.E. – See also WAGENBLAST, H.

GAILLOUD, M. – See BALTAY, C.; FERBEL, T.

GALBRAITH, W., JENKINS, E.W., KYCIA, T.F., LEONTIC, B.A., PHILLIPS, R.H., READ, A.L., AND RUBINSTEIN, R. Total cross sections of protons, antiprotons, pi and K mesons on hydrogen and deuterium in the momentum range 4-22 GeV/*c*. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

GALLMANN, A. – See WARBURTON, E.K.

GAMBLE, F.T., BARTRAM, R.H., YOUNG, C.G., GILLIAM, O.R., AND LEVY, P.W. Electron-spin resonances in gamma-ray-irradiated aluminum oxide. *Phys. Rev.* **134**, A589-95 (1964).

GERHOLM, T.R. AND CHURCH, E.L. Coincidence Orange spectrometer counter. (A) *Bull. Am. Phys. Soc.* **9**, 46 (1964).

GERHOLM, T.R. – See also CHURCH, E.L.

GILLIAM, O.R. – See GAMBLE, F.T.

GILMORE, R.S. – See FOLEY, K.J.

GLASSER, R.G. – See BURNSTEIN, R.A.; COURANT, H.

GLASSGOLD, A.E. AND LEBEDEFF, S.A. Scattering amplitudes for atomic collisions, with application to spin-exchange between hydrogen atoms. *Ann. Phys. N.Y.* **28**, 181 (1964).

GOLAND, A.N. AND PASKIN, A. Model for fission-fragment damage in thin polycrystalline metal films. *J. Appl. Phys.* **35**, 2188-94 (1964).

GOLAND, A.N. – See also CHOI, C.S.; KELSCH, J.J. (Nuclear Engineering).

GOLDHABER, G.S. – See TAKAHASHI, K.

GOLDHABER, M. AND SUNYAR, A.W. Classification of nuclear isomers. In *Alpha-, Beta-, and Gamma-Ray Spectros-*

copy, 2nd Ed., K. Sieghbahn, Editor, North-Holland, Amsterdam (in press).

GOLDHABER, M. – See also SCHWARZSCHILD, A.

GONZALO, J.A. AND ARNDT, R.A. Polar anisotropy centers in γ-irradiated TGS. (A) *Bull. Am. Phys. Soc.* **9**, 491 (1964).

GOODINGS, D.A. AND MOZER, B. A treatment of the metallic impurity problem using Green's functions. Submitted to *Phys. Rev.*

GOODINGS, D.A. – See also MOZER, B.

GOODZEIT, C.L. 80-in. Bubble chamber expansion system: Preliminary operating procedures. Informal Report BNL 7493.

GOODZEIT, C.L. 80-in. Bubble chamber expansion system: Summary of piston motion studies. Informal Report BNL 7490.

GOODZEIT, C.L. Evaluation of stainless steel casting alloys for cryogenic service in the 80-in. bubble chamber. *Proc. Cryogenic Engineering Conf., Philadelphia, Aug. 1964* (in press).

GOODZEIT, C.L. Expansion system status report. Informal Report BNL 7486.

GOODZEIT, C.L. Selecting reservoir sizes for 80-in. bubble chamber expansion system. Informal Report BNL 7482.

GOODZEIT, C.L. – See also DIENER, J.J.

GOUDSMIT, S.A. AND RICHARDS, P.I. The order of electron shells in ionized atoms. *Proc. Natl. Acad. Sci. U.S.* **51**, 664-71 (1964).

GOULD, C. Bubble chamber vacuum system. Informal Report BNL 7478.

GOZ, B. AND WEBSTER, M.S. Shimming of bending magnets. Informal Report BNL 8141.

GOZ, B. – See also BARNES, V.E.

GREGORY, B. Remarks on curvature and angle measurements in a hydrogen bubble chamber. Informal Report BNL 7933.

GRIFFEL, M. – See JACH, J.

GUNDZIK, M. – See BARNES, V.E.; CONNOLLY, P.L.; LAI, K.W.; LICHTMAN, S.; LONDON, G.W.

HADDAD, E. – See PALEVSKY, H.

HAGERTY, P.E. – See BARNES, V.E.

HART, E.L. Film format and fiducial marks of the 20-in. bubble chamber. Informal Report BNL 7897.

HART, E.L. Revised optical constants for the BNL 20-in. chamber. Informal Report BNL 7896.

HART, E.L., CONNOLLY, P.L., RAHM, D.C., STONEHILL, D.L., YAMAMOTO, S.S., AND WILLIS, W.J. The reaction $K^- + p \rightarrow \Lambda + \eta$ near threshold. (A) *Bull. Am. Phys. Soc.* **9**, 24 (1964).

HART, E.L. – See also BARNES, V.E.; CONNOLLY, P.L.; LAI, K.W.; LICHTMAN, S.; LONDON, G.W.

HATCHER, R.D. AND DIENES, G.J. Relaxation and activation energies for an interstitial neutral defect in an alkali halide lattice. II. *Phys. Rev.* **134**, A214-26 (1964).

HEPP, V. – See COURANT, H.

HERZ, A.J. – See BURNSTEIN, R.A.; COURANT, H.

HIEN, N.C. – See TURKOT, F.

HILL, D.A., LI, K.K., JENKINS, W.E., KYCIA, T.F., AND RUDERMAN, H. Measurement of the lambda magnetic moment. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

HOOT, C. – See RICKEY, M.E.

HOPKINS, H.W.K. – See BACON, T.C.

HORWITZ, N. AND WEBSTER, M. Čerenkov counter monitor for separated bubble chamber beams. *Rev. Sci. Instr.* (in press).

HORWITZ, N. – See also BARNES, V.E.

HOSIE, J.W. – See CULWICK, B.B.

HOUGH, P.V.C. Attempts to obtain high rate, high quality measurement of events despite FILTER II imperfections. In *Proc. Conf. Programming for HPD and Other Flying Spot Devices, Collège de France, Paris, Aug. 1963*, CERN 63-34, pp. 133-9, CERN, Geneva, 1963.

HOUGH, P.V.C. Comparison of rapid data processing systems. Informal Report BNL 7871.

HOUGH, P.V.C. Man-machine collaboration in the analysis of bubble chamber photographs for high-energy physics. Submitted to *Soc. Phot. Instrumentation Engrs. J.*

HOUGH, P.V.C. – See also BARNES, V.E.; CONNOLLY, P.L.

IKEGAMI, H. AND EMERY, G.T. Evidence for the excitation of two-particle one-hole configurations in the capture of thermal neutrons. (L) *Phys. Rev. Letters* **13**, 26-9 (1964).

IKEGAMI, H. AND UDAGAWA, T. Effect of pairing correlations on nuclear gamma-ray transitions. *Phys. Rev.* **133**, B1388-1400 (1964).

JACH, J. Thermal decomposition at defects. *Proc. 5th Intern. Symp. Reactivity of Solids, Munich, Aug. 1964* (in press).

JACH, J. AND GRIFFEL, M. The thermal decomposition of irradiated nickel oxalate. *J. Phys. Chem.* **68**, 731-6 (1964).

JAIN, A.P. Diffuseness of the nuclear surface from *S*-wave strength functions. *Phys. Rev.* **132**, 774-5 (1963).

JAIN, A.P. The relationship between the optical model and the resonance theory. *Phys. Rev.* **134**, B1-7 (1964).

JAIN, A.P. *S* and *P*-wave strength functions and the surface absorption optical model. *Nucl. Phys.* **50**, 157-70 (1964).

JAIN, A.P., CHRIEN, R.E., MOORE, J.A., AND PALEVSKY, H. Parameters of the 132-eV neutron resonance in Co^{59}. *Nucl. Sci. Eng.* **17**, 319-24 (1963).

JAIN, A.P., CHRIEN, R.E., MOORE, J.A., AND PALEVSKY, H. Total neutron average cross sections in the keV region and the optical model. (A) *Bull. Am. Phys. Soc.* **9**, 166 (1964).

JAIN, A.P. – See also MUGHABGHAB, S.

JANIK, J.A., JANIK, J.M., MELLOR, J., AND PALEVSKY, H. Study of molecular rotations in solids and liquids by the inelastic scattering of cold neutrons. *J. Phys. Chem. Solids* **25**, 1091-8 (1964).

JANIK, J.M. – See JANIK, J.A.

JENKINS, E.W., BAKER, W.F., READ, A.L., ULRICH, B.T., COCCONI, G., COCCONI, V.T., KRISCH, A.D., OREAR, J., RUBINSTEIN, R., AND SCARL, D. Measurement of $p + p \rightarrow \pi^+ + D$ at high-momentum transfers. (A) *Bull. Am. Phys. Soc.* **8**, 617 (1963).

JENKINS, E.W. – See also DIDDENS, A.N.; GALBRAITH, W.; HILL, D.A.; RILEY, K.F.

JENSEN, J.E. – See BAMBERGER, J.A.; BARNES, V.E.

JOHNSON, R.A. Interstitials and vacancies in α-iron. *Phys. Rev.* **134**, A1329-36 (1964).

JOHNSON, R.A. AND DAMASK, A.C. Point defect configurations in irradiated iron-carbon alloys. (L) *Acta Met.* **12**, 443-5 (1964).

JOHNSON, R.A., DIENES, G.J., AND DAMASK, A.C. Calculations of the energy and migration characteristics of carbon and nitrogen in α-iron and vanadium. *Acta Met.* (in press).

JOHNSON, R.A. – See also DAMASK, A.C.

JONA, F. – See BOUTIN, H.

JONES, K.W. – See RICKEY, M.E.

KACSER, C. The analytic structure of partial wave amplitudes for production and decay processes. *Phys. Rev.* **132**, 2712-21 (1963).

KACSER, C. – See also AITCHISON, I.J.R.

KALBFLEISCH, G. – See CONNOLLY, P.L.

KALBITZER, S. AND LEVY, P.W. Growth and annealing of *F* centers in gamma-ray-irradiated KCl. (A) *Bull. Am. Phys. Soc.* **9**, 262 (1964).

KALOGEROPOULOS, T. – See BARNES, V.E.

KAN, H.K.A. – See TOWNSEND, P.D.

KANE, J.V. AND SPINRAD, R.J. A stored program computer as a multiparameter radiation analyzer. *Nucl. Instr. Methods* **25**, 141-8 (1963).

KANE, J.V. – See also DONOVAN, P.F. (Chemistry); MOLLENAUER, J.F. (Chemistry).

KANE, W.R. – See CRASEMANN, B.

KANTOR, P.B. Nucleon-nucleon scattering and the meson resonances. (L) *Phys. Rev. Letters* **12**, 52-4 (1964).

KASSNER, D.A. Design consideration for 80-in. bubble chamber. Informal Report BNL 7495.

KEHOE, B. – See BURNSTEIN, R.A.; COURANT, H.

KELLER, J.M. Resistivity of vacancy impurity pairs. *J. Phys. Chem. Solids* **24**, 1121 (1963).

KEMP, M.A.R. – See TURKOT, F.

KENNEY, V.P. – See FABIAN, B.N.

KEVEY, A. *Universal Spectrometer I.* BNL 851 (T-337), March 1964.

KISTNER, O.C., LI, A.C., AND MONARO, S. Lifetimes of the 22-keV first excited states in Eu^{151} and Sm^{149}. *Phys. Rev.* **132**, 1733-5 (1963).

KISTNER, O.C., MONARO, S., AND SEGNAN, R. Recoilless resonance absorption in Ru^{99}. (L) *Phys. Letters* **5**, 299 (1963).

KISTNER, O.C. AND SEGNAN, R. Properties of the 90-keV mixed transition in ^{99}Ru determined from recoilfree resonance measurements. (A) *Bull. Am. Phys. Soc.* **9**, 396 (1964).

KISTNER, O.C. – See also CHU, Y.Y. (Chemistry); CRAIG, P.P.

KLUGE, E. – See COURANT, H.

KOCHER, W.C. AND MOZER, B. Recoilless radiation absorption by Fe^{57} in iron-vanadium alloys. (A) *Bull. Am. Phys. Soc.* **8**, 600 (1963).

KONDO, M. – See RICKEY, M.E.

KOPP, J.K. – See BALTAY, C.; BARNES, V.E.

KRAYBILL, H.L. Illumination of 80-in. chamber. Informal Report BNL 7806.

KRAYBILL, H.L. Retrodirectors. Informal Report BNL 7807.

KRAYBILL, H.L. – See also FOWLER, E.

KRISCH, A.D. – See JENKINS, E.W.

KUO, T.K. On a model for the $\pi\omega$ resonance at 1220 MeV. (L) *Phys. Rev. Letters* **12**, 465-7 (1964).

KURIYAMA, M., FLINN, P.A., COX, D.E., AND SHIRANE, G. Mössbauer study of the magnetic properties of the Cr_2O_3–Fe_2O_3 system. (A) Presented at 3rd Intern. Conf. Mössbauer Effect, Ithaca, N.Y., Sept. 1963.

KYCIA, T.F. – See DIDDENS, A.N.; GALBRAITH, W.; HILL, D.A.; RILEY, K.F.; TEPPER, L. (Instr. & Health Physics).

LAI, K.W., CONNOLLY, P.L., HART, E.L., LONDON, G.W., MONETI, G.C., RAU, R.R., SAMIOS, N.P., SKILLICORN, I.O., YAMAMOTO, S.S., GOLDBERG, M., GUNDZIK, M., LEITNER, J., AND LICHTMAN, S. Production and decay of the ϕ meson. (A) *Bull. Am. Phys. Soc.* **9**, 22 (1964).

LAI, K.W. – See also BARNES, V.E.; CONNOLLY, P.L.; LICHTMAN, S.; LONDON, G.W.

LARSEN, R.E. Radiation enhanced diffusion in α-brass. (A) Presented at AIME Meeting, New York, Feb. 1964.

LARSEN, R.E. AND DAMASK, A.C. Gamma-ray enhanced diffusion in α-brass. *Acta Met.* **12**, 1131-9 (1964).

LARSEN, R.E., DIENES, G.J., AND DAMASK, A.C. Flux dependence of neutron-enhanced diffusion in α-brass. *Acta Met.* **12**, 1141-6 (1964).

LEA, R.M. – See BALTAY, C.; BARNES, V.E.; FERBEL, T.; FOWLER, E.

LEBEDEFF, S.A. – See GLASSGOLD, A.E.

LEDERMAN, L.M. *Neutrino Physics, Brookhaven Lecture Series No. 23, Jan. 9, 1963.* BNL 787 (T-300).

LEDERMAN, L.M. – See also COMSTOCK, M. (Information).

LEITNER, J. – See BARNES, V.E.; CONNOLLY, P.L.; LAI, K.W.; LICHTMAN, S.; LONDON, G.W.

LEONTIC, B.A. – See GALBRAITH, W.

LEVIN, F.S. Target excitation effects in deuteron stripping. (A) *Bull. Am. Phys. Soc.* **9**, 466 (1964).

LEVY, P.W. The use of color centers for the detection and measurement of defects. *Am. Soc. Testing Mater. Spec. Tech. Publ.* **359**, 3-19 (1964).

LEVY, P.W. – See also AGULLO-LÓPEZ, F.; GAMBLE, F.T.; KALBITZER, S.; TOWNSEND, P.D.

LI, A.C. – See BARGE, D.A. (Accelerator); CHU, W.T. (Accelerator); CHU, Y.Y. (Chemistry); KISTNER, O.C.

LI, K.K. – See HILL, D.A.

LICHTMAN, S., GOLDBERG, M., GUNDZIK, M., LEITNER, J., CONNOLLY, P.L., HART, E.L., LAI, K.W., LONDON, G.W., MONETI, G.C., RAU, R.R., SAMIOS, N.P., SKILLICORN, I.O., AND YAMAMOTO, S.S. The ϕ spin and kaon statistics. (A) *Bull. Am. Phys. Soc.* **9**, 22 (1964).

LICHTMAN, S. – See also CONNOLLY, P.L.; LAI, K.W.; LONDON, G.W.

LINDENBAUM, S.J. High energy elastic scattering of $\pi^{\pm}$, p, $\bar{p}$ and $K^{\pm}$ by protons, and Regge Pole predictions. In *Nucleon Structure (Proc. Conf., Stanford University, Aug. 1963)*, pp. 105-30, R. Hofstadter and L.I. Schiff, Editors, Stanford University Press, 1964.

LINDENBAUM, S.J. – See also FOLEY, K.J.

LIPWORTH, E. – See COHEN, V.W.

LLOYD, J.L., SMITH, J.R., AND YAMAMOTO, S.S. Final state interactions in $\pi^+ + p$ collisions at 2.77 BeV/c. (A) Presented at Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964.

LLOYD, J.L. – See also BARNES, V.E.

LONDON, G.W., CONNOLLY, P.L., HART, E.L., LAI, K.W., MONETI, G.C., RAU, R.R., SAMIOS, N.P., SKILLICORN, I.O., YAMAMOTO, S.S., GOLDBERG, M., GUNDZIK, M., LEITNER, J., AND LICHTMAN, S. Properties of the Ξ^- and Ξ^0 hyperons. (A) *Bull. Am. Phys. Soc.* **9**, 22 (1964).

LONDON, G.W. – See also BARNES, V.E.; CONNOLLY, P.L.; LAI, K.W.; LICHTMAN, S.

LOPEZ, W.M. – See PALEVSKY, H.

LOUTTIT, R.I. – See BALTAY, C.

LOVE, W.A. – See FOLEY, K.J.

LOWE, J. AND MCCLELLAND, C.L. Lifetime measurements on the first excited states of O^{17} and F^{18}. *Phys. Rev.* **132**, 367-71 (1963).

LUERS, D., MITTRA, I.S., WILLIS, W.J., AND YAMAMOTO, S.S. K_2^0 decay. *Phys. Rev.* **133**, B1276-89 (1964).

MCCLELLAND, C.L. – See LOWE, J.

MCGEE, I.J. Study of some experimental data on K-meson decays. Informal Report BNL 8094.

MCKEOWN, M. – See TAKAHASHI, K.

MELLOR, J. – See JANIK, J.A.; OTNES, K.; SUTTER, R.J.

MELTZER, C.M. – See BACON, T.C.

MENES, J. – See TURKOT, F.

MINGUZZI-RANZI, A. – See BURNSTEIN, R.A.; COURANT, H.

MITCHELL, G.E. – See BECKER, J.A.

MITTRA, I.S. – See LUERS, D.

MO, S.C. Coil stresses due to magnetic forces. Informal Report BNL 7483.

MO, S.C. Stresses in 80-in. bubble chamber magnet coil (preliminary report.) Informal Report BNL 7485.

MO, S.C. Structural analysis of 80-in. bubble chamber magnet return iron. Informal Report BNL 7484.

MONARO, S. Excited levels in ^{77}Se from the decay of ^{77}Br. *Nuovo Cimento* **30**, 1379-95 (1963).

MONARO, S. – See also CHU, Y.Y. (Chemistry); KISTNER, O.C.

MONETI, G. – See BARNES, V.E.; CONNOLLY, P.L.; LAI, K.W.; LICHTMAN, S.; LONDON, G.W.; YAMAMOTO, S.S.

MOORE, J.A., PALEVSKY, H., AND CHRIEN, R.E. Neutron capture in iron. *Phys. Rev.* **132**, 801-6 (1963).

MOORE, J.A. – See also JAIN, A.P.

MORAN, T.I. – See COHEN, V.W.

MORRIS, T.W. – See BALTAY, C.; BARNES, V.E.; FERBEL, T.

MOZER, B. Anharmonic broadening of a localized mode of vibration. (A) *Bull. Am. Phys. Soc.* **8**, 593 (1963).

MOZER, B. AND GOODINGS, D.A. Interpretation of the soft x-ray emission spectrum of lithium metal. Submitted to *Phys. Rev.*

MOZER, B. AND GOODINGS, D.A. X-ray emission spectra of metals and the metallic impurity problem. (A) Presented at Am. Phys. Soc. Meeting, Philadelphia, March 1964.

MOZER, B., OTNES, K., AND PALEVSKY, H. Measured vibrational frequency distributions of Ni, V, Ti and $Ti_{.67}$-$Zr_{.33}$. *Proc.. Intern. Meeting Lattice Dynamics, Copenhagen, Aug. 1963* (in press).

MOZER, B. – See also CRAIG, P.P.; GOODINGS, D.A.; KOCHER, W.C.; SEGNAN, R.

MUETHER, H.R., STEARNS, R.L., CHRIEN, R.E., FRIEDES, J.L., SUTTER, R.J., OTNES, K., AND PALEVSKY, H. "Monoenergetic" neutron beams from the Brookhaven Cosmotron. (A) *Bull. Am. Phys. Soc.* **9**, 94 (1964).

MUETHER, H.R. – See also PALEVSKY, H.; SUTTER, R.J.

MUGHABGHAB, S., JAIN, A.P., AND CHRIEN, R.E. Resonance parameters of the dysprosium and gadolinium isotopes. (A) *Bull. Am. Phys. Soc.* **9**, 433 (1964).

MUGHABGHAB, S. – See also FRIEDES, J.L.

MUNIR, B.A. – See PICKUP, E.

MYERS, V.W. – See FRIEDES, J.L.

NATHANS, R. AND PICKART, S.J. Neutron magnetic scattering from f.c.c. iron alloys. *J. Phys. Chem. Solids* **25**, 183-6 (1964).

NATHANS, R. – See also PICKART, S.J.; SHIRANE, G.; WILL, G.

NIELSEN, P. – See PASSELL, L.

NIERENBERG, W.A. – See CHAN, Y.W.

OLNESS, J.W. – See BREDIN, D.J.; WARBURTON, E.K.

OOSTENS, J. – See TURKOT, F.

OREAR, J. – See JENKINS, E.W.; READ, A.L.

OREN, Y. AND STRAND, R.C. Progress report on HPD bubble density measurements. Informal Report BNL 7769.

OREN, Y. – See also BARNES, V.E.

OTNES, K., MELLOR, J., AND PALEVSKY, H. The spectra of scattered cold neutrons from gaseous, liquid, and solid methane. (A) *Bull. Am. Phys. Soc.* **9**, 421 (1964).

OTNES, K. – See also MOZER, B.; MUETHER, H.R.

OZAKI, S. – See FOLEY, K.J.

PALEVSKY, H. Inelastic neutron scattering by liquids. *Proc. General Motors Symp. Liquids – Structure, Properties, Solid Interactions, Warren, Mich., Sept. 1963* (in press).

PALEVSKY, H. Use of cold neutrons in solid state research. *Proc. Conf. Nuclear Spectroscopy and Solid State Physics, Lima, Feb. 1964* (in press).

PALEVSKY, H., CHRIEN, R.E., HADDAD, E., AND LOPEZ, W.M. Self-indication analysis of Breit-Wigner levels and some results using this method for the low energy resonances in thorium. (A) *Bull. Am. Phys. Soc.* **9**, 20 (1964).

PALEVSKY, H., FRIEDES, J.L., SUTTER, R.J., CHRIEN, R.E., AND MUETHER, H.R. Neutron-nucleon interactions in the GeV energy region. *Proc. Intern. Conf. Nuclear Physics, Paris, July 1964* (in press).

PALEVSKY, H. – See also CHRIEN, R.E.; FRIEDES, J.L.; JAIN, A.P.; JANIK, J.A.; MOORE, J.A.; MOZER, B.; MUETHER, H.R.; OTNES, K.; SUTTER, R.J.

PALMER, R.B. Early tests on the BNL Mark II HPD. Informal Report BNL 7675.

PALMER, R.B. – See also BARNES, V.E.

PARKER, P.D. – See ALBURGER, D.E.; DONOVAN, P.F. (Chemistry).

PASSELL, L., BLINOWSKI, K., BRUN, T., AND NIELSEN, P. Critical magnetic scattering of neutrons in iron. *J. Appl. Phys.* **35**, 933-4 (1964).

PASSELL, L., SAILOR, V.L., AND SCHERMER, R.I. Nuclear polarization in EuS and Eu. *Phys. Rev.* (in press).

PATON, J.E. – See CHAN, H.M.

PEIERLS, R.F. Possible interpretation of the $\pi\omega$ resonance at 1220 MeV. (L) *Phys. Rev. Letters* **12**, 50-2 (1964).

PEIERLS, R.F. AND TRUEMAN, T.L. Restrictions imposed by the optical theorem on exchanged quantum numbers. *Phys. Rev.* **134**, B1365-7 (1964).

PENSELIN, S. – See COHEN, V.W.

PHILLIPS, R.H. – See GALBRAITH, W.; RILEY, K.F.

PICKART, S.J., ALPERIN, H.A., AND NATHANS, R. Magnetic structure of binary fluorides containing Mn^{2+}. *J. Phys. Radium* (in press).

PICKART, S.J., ALPERIN, H.A., SHIRANE, G., AND NATHANS, R. Itinerant electron ferromagnetism in $ZrZn_2$. (L) *Phys. Rev. Letters* **12**, 444-7 (1964).

PICKART, S.J., ALPERIN, H.A., SHIRANE, G., AND NATHANS, R. Spin density in ferromagnetic $ZrZn_2$. (A) *Bull. Am. Phys. Soc.* **9**, 212 (1964).

PICKART, S.J., NATHANS, R., AND ALPERIN, H.A. Spin density of the canted moment in α-Fe_2O_3. *J. Phys. Radium* (in press).

PICKART, S.J. – See also NATHANS, R.; SHIRANE, G.; WILL, G.

PICKUP, E., ROBINSON, D.K., AND SALANT, E.O. Departures from one-pion exchange in 1.25-BeV π^--p interactions. (L) *Phys. Rev. Letters* **9**, 170 (1962).

PICKUP, E., ROBINSON, D.K., SALANT, E.O., AYER, F., AND MUNIR, B.A. π^--p Interactions at 905, 960 and 1100 MeV. *Phys. Rev.* **132**, 1819-30 (1963).

PLACE, R.L. – See FABIAN, B.N.

POSTMA, H., SHORE, F.J., AND REYNOLDS, C.A. Absolute determination of spins of neutron resonances in terbium-159 by a weighting factor method using polarized neutrons and a polarized Tb target. *Physica* **30**, 713-28 (1964).

PRODELL, A., FISCHER, V.K., BASTIEN, P., EISENBERG, Y., FELD, B.T., PLESS, I.A., ROGERS, A., ROGERS, C., ROSENSON, L., YAMAMOTO, R.K., WIDGOFF, M., SHAPIRO, A.M., LANOU, R.E., BULOS, F., BRENNER, A.E., LAW, M.E., RONAT, E.E., STRAUCH, K., STREET, J.C., SZYMANSKI, J.J., TEAL, J.D., GUERRIERO, L., SALANDIN, G.A., AND FISCHER, G.E. Three-pion production in a 5-BeV bremsstrahlung beam. (A) *Bull. Am. Phys. Soc.* **9**, 409 (1964).

PRODELL, A., SZYMANSKI, J.J., BRENNER, A.E., LAW, M.E., RONAT, E.E., STRAUCH, K., STREET, J.C., TEAL, J.D., WIDGOFF, M., SHAPIRO, A.M., LANOU, R.E., BULOS, F., BASTIEN, P., EISENBERG, Y., FELD, B.T., FISCHER, V.K., PLESS, I.A., ROGERS, A., ROGERS C., ROSENSON, L., YAMAMOTO, R.K., GUERRIERO, L., SALANDIN, G.A., AND FISCHER, G.E. Pion pair production in a 5-BeV bremsstrahlung beam. (A) *Bull. Am. Phys. Soc.* **9**, 408 (1964).

PRODELL, A., WIDGOFF, M., SHAPIRO, A.M., LANOU, R.E., BULOS, F., BRENNER, A.E., LAW, M.E., RONAT, E.E., STRAUCH, K., STREET, J.C., SZYMANSKI, J.J., TEAL, J.D., BASTIEN, P., EISENBERG, Y., FELD, B.T., FISCHER, V.K., PLESS, I.A., ROGERS, A., ROGERS, C., ROSENSON, L., YAMAMOTO, R.K., GUERRIERO, L., SALANDIN, G.A., AND FISCHER, G.E. Photonucleon interactions in a 5-BeV bremsstrahlung beam. (A) *Bull. Am. Phys. Soc.* **9**, 381 (1964).

PRODELL, A. – See also ALFF, C. (Accelerator); BARNES, V.E.

RADOJICIC, D. – See BARNES, V.E.; CONNOLLY, P.L.; HART, E.L.; YAMAMOTO, S.S.

RAU, R.R. Coordinate determination in bubble chambers. Informal Report BNL 8142.

RAU, R.R. 80-in. Chamber – Low energy beams. Informal Report BNL 7480.

RAU, R.R. – See also CONNOLLY, P.L.; LAI, K.W.; LICHTMAN, S.; LONDON, G.W.

READ, A.L., OREAR, J., AND BETHE, H.A. Exact form for scattering amplitude in Regge pole theory. *Nuovo Cimento* **29**, 1051-8 (1963).

READ, A.L. – See also GALBRAITH, W.; JENKINS, E.W.; RILEY, K.F.

REYNOLDS, C.A. – See POSTMA, H.; SHORE, F.J.

RICHARDSON, C.R. – See BARNES, V.E.

RICKEY, M.E. AND WEGNER, H.E. Two-neutron pickup reaction $Mg^{26}(He^4,He^6)Mg^{24}$. (A) *Bull. Am. Phys. Soc.* **9**, 78 (1964).

RICKEY, M.E., WEGNER, H.E., JONES, K.W., BARDIN, B.M., HOOT, C., AND KONDO, M. A study of the nuclear reactions $Mg^{26}(p,t)Mg^{24}$ and $Mg^{26}(He^4,He^6)Mg^{24}$. *Proc. Symp. Nuclear Spectroscopy With Direct Reactions, Argonne National Laboratory, March 1964* (in press).

RILEY, K.F., BAKER, W.F., JENKINS, E.W., KYCIA, T.F., PHILLIPS, R.H., READ, A.L., AND RUDERMAN, H. Total cross sections for K mesons and π mesons on protons and deuterons between 2.5 and 6 BeV/c. *Proc. Intern. Conf. Elementary Particles, Sienna, Italy, Oct. 1963* (in press).

RILEY, K.F. – See also DIDDENS, A.N.; FABIAN, B.N.

RISTINEN, R.A. AND SUNYAR, A.W. Gyromagnetic ratio of the 68-keV first excited state in Sc^{44}. (A) *Bull. Am. Phys. Soc.* **9**, 451 (1964).

ROBINSON, D.K. – See BACON, T.C.; PICKUP, E.

ROSENBLATT, D.B. AND DIENES, G.J. *The Effect of Reactor Irradiation Upon Hydrogen Adsorption by an Alumina Catalyst.* BNL 845 (T-332), Feb. 1964.

RUBINSTEIN, R. – See GALBRAITH, W.; JENKINS, E.W.

RUDERMAN, H. – See HILL, D.A.; RILEY, K.F.

RUSTAD, B.M. – See VISE, J.B.

SAFFORD, G.J., DANNER, H.R., BOUTIN, H., AND BERGER, M. An investigation of the low frequency motions in isotactic and atactic polypropylene by neutron inelastic scattering. *J. Chem. Phys.* **40**, 1426-32 (1964).

SAFFORD, G.J. – See also BOUTIN, H.; DANNER, H.R.

SAILOR, V.L. – See SHORE, F.J.; PASSELL, L.

SAKITT, M. – See COURANT, H.

SALANT, E.O. – See BACON, T.C.; PICKUP, E.

SAMIOS, N.P. – See BARNES, V.E.; CONNOLLY, P.L.; LAI, K.W.; LICHTMAN, S.; LONDON, G.W.

SANDWEISS, J. AND SANFORD, J.R. Beam II program. Informal Report BNL 7719.

SANDWEISS, J. – See also BALTAY, C.; FERBEL, T.; FOWLER, E.

SANFORD, J.R. – See BALTAY, C.; BARNES, V.E.; FOWLER, E.; SANDWEISS, J.

SCARL, D. – See JENKINS, E.W.

SCHERMER, R.I. – See PASSELL, L.

SCHNECKE, J.C. SYSTEM. Informal Report BNL 7680.

SCHWARZSCHILD, A., POSKANZER, A.M., EMERY, G.T., AND GOLDHABER, M. Another search for H^5. *Phys. Rev.* **133**, B1-2 (1964).

SCHWARZSCHILD, A. – See also CHURCH, E.L.

SEEMAN, N. – See BURNSTEIN, R.A.; COURANT, H.

SEGAR, A. – See BURNSTEIN, R.A.; COURANT, H.

SEGNAN, R. AND CRAIG, P.P. Mössbauer measurements in external magnetic fields near the Curie temperature. (A) Presented at 9th Intern. Conf. Low Temperature Physics, Columbus, Ohio, Sept. 1964.

SEGNAN, R. AND MOZER, B. Isomer shift and electric quadrupole coupling measurements in several hexagonal close packed metals. (A) Presented at 3rd Intern. Conf. Mössbauer Effect, Ithaca, N.Y., Sept. 1963.

SEGNAN, R. – See also CRAIG, P.P.; KISTNER, O.C.

SHIMIZU, A., ERGINSOY, C., AND VINEYARD, G.H. Influence of crystal lattice on damage processes. (A) *Bull. Am. Phys. Soc.* **9**, 397 (1964).

SHIRANE, G., COX, D.E., AND PICKART, S.J. Magnetic structures in $FeCr_2S_4$ and $FeCr_2O_4$. *J. Appl. Phys.* **35**, 954-5 (1964).

SHIRANE, G., NATHANS, R., AND CHEN, C.W. Magnetic moments and unpaired spin densities in the Fe-Rh alloys. *Phys. Rev.* **134**, A1547-53 (1964).

SHIRANE, G. – See also COX, D.E.; KURIYAMA, M.; PICKART, S.J.; WILL, G.

SHORE, F.J., SAILOR, V.L., BRUNHART, G., AND REYNOLDS, C.A. Spins of neutron resonances and the hyperfine field in gadolinium metal. (A) *Bull. Am. Phys. Soc.* **9**, 21 (1964).

SHORE, F.J. – See also POSTMA, H.

SHUTT, R.P. Considerations on diaphragm springs. Informal Report BNL 8143.

SHUTT, R.P. Considerations on the magnet for the 80-in. bubble chamber. Informal Report BNL 7479.

SHUTT, R.P. Pressure variations due to the liquid column in the neck of the 80-in. chamber. Informal Report BNL 8091.

SHUTT, R.P. Some design parameters for the 80-in. hydrogen bubble chamber. Informal Report BNL 8144.

SHUTT, R.P. – See also BALTAY, C.; BARNES, V.E.

SIMS, W.H. – See FABIAN, B.N.

SKILLICORN, I.O. AND WEBSTER, M.S. Status report on a high energy separated beam for the 80-in. chamber. Informal Report BNL 8145.

SKILLICORN, I.O. – See also CONNOLLY, P.L.; LAI, K.W.; LICHTMAN, S.; LONDON, G.W.; YAMAMOTO, S.S.

SMITH, J.R. – See BARNES, V.E.; LLOYD, J.L.

SNOW, G.A. – See BURNSTEIN, R.A.; COURANT, H.

SORENSEN, R.A. Electric quadrupole transitions in odd-mass spherical nuclei. Submitted to *Phys. Rev.*

STEARNS, R.L. – See MUETHER, H.R.

STERNHEIM, M.M. – See ALLEN, P.B.

STERNHEIMER, R.M. Empirical relations involving the hyperons and baryon isomers. *Phys. Rev.* **131**, 2698-703 (1963).

STERNHEIMER, R.M. Empirical systematics of the strongly interacting particles. (L) *Phys. Rev. Letters* **13**, 37-40 (1964).

STERNHEIMER, R.M. Quadrupole antishielding factors of ions. (A) *Bull. Am. Phys. Soc.* **9**, 14 (1964).

STERNHEIMER, R.M. Quadrupole antishielding factors of ions. *Phys. Rev.* **132**, 1637-9 (1963).

STERNHEIMER, R.M. Wave functions for quadrupole antishielding factors. *Phys. Rev.* **130**, 1423-5 (1963).

STONEHILL, D.L. The SUFFOLK COUNTY FAIR. Informal Report BNL 7636.

STONEHILL, D.L. The SUFFOLK COUNTY FAIR system. Informal Report BNL 7637.

STONEHILL, D.L. Wild ideas on bookkeeping system. Informal Report BNL 7895.

STONEHILL, D.L. – See also BALTAY, C.; BARNES, V.E.; CONNOLLY, P.L.; HART, E.L.

STRAND, R.C. Bubble density measurement with the Hough-Powell digitizer. Informal Report BNL 7187.

STRAND, R.C. Preliminary plans for use of Hough-Powell bubble density measurements. Informal Report BNL 7186.

STRAND, R.C., THORNDIKE, A.M., AND WEBRE, N.W. Automatic bubble density measurement with the Hough-Powell system. Informal Report BNL 7375.

STRAND, R.C. – See also BARNES, V.E.; CONNOLLY, P.L.; OREN, Y.

STRONGIN, M., PASKIN, A., SCHWEITZER, D.G., KAMMERER, O.F., AND CRAIG, P.P. Surface superconductivity in type I and type II superconductors. (L) *Phys. Rev. Letters* **12**, 442-4 (1964).

STRONGIN, M., SCHWEITZER, D.G., PASKIN, A., AND CRAIG, P.P. Magnetic field penetration and breakdown of surface superconductivity. *Phys. Rev.* (in press).

STRONGIN, M. – See also PASKIN, A. (Nuclear Engineering); SCHWEITZER, D.G. (Nuclear Engineering).

STUMP, R. – See BALTAY, C.

SUNYAR, A.W. Third-lifetime component in the annihilation of positrons in amorphous solids and plastics. (A) *Bull. Am. Phys. Soc.* **9**, 394 (1964).

SUNYAR, A.W. – See also GOLDHABER, M.; RISTINEN, R.A.

SUTTER, R.J., MELLOR, J., MUETHER, H.R., AND PALEVSKY, H. A neutron-scintillation detector with low gamma-ray sensitivity. (A) *Bull. Am. Phys. Soc.* **9**, 47 (1964).

SUTTER, R.J. – See also FRIEDES, J.L.; MUETHER, H.R.; PALEVSKY, H.

TAFT, H.D. – See BALTAY, C.

TAKAHASHI, K., MCKEOWN, M., AND GOLDHABER, G.S. The isomer Re^{188m}. *Phys. Rev.* (in press).

TAKEI, W.J. – See COX, D.E.

THOMPSON, W.M. – See CONNOLLY, P.L.

THORNDIKE, A.M. Background information near "4° beam." Informal Report BNL 8096.

THORNDIKE, A.M. Data reduction computation. Informal Report BNL 8097.

THORNDIKE, A.M. Operating instructions – TRED 704. Informal Report BNL 8098.

THORNDIKE, A.M. Rough estimation of momentum error. Informal Report BNL 8146.

THORNDIKE, A.M. – See also BALTAY, C.; BARNES, V.E.; CULWICK, B.B.; FOWLER, E.; STRAND, R.C.

TOWNSEND, P.D., KAN, H.K.A., AND LEVY, P.W. Effects of irradiation on the optical absorption and photoconductivity of rutile. *Proc. Brit. Ceram. Soc.* **1**, 71-83 (1964).

TRUEMAN, T.L. AND WICK, G.C. Crossing relations for helicity amplitudes. *Ann. Phys. N.Y.* **26**, 322-35 (1964).

TRUEMAN, T.L. AND YAO, T. High energy scattering amplitude in perturbation theory. *Phys. Rev.* **132**, 2741-8 (1963).

TRUEMAN, T.L. – See also PEIERLS, R.F.

TURKOT, F., COLLINS, G.B., AND FUJII, T. Deuteron production in *p-p* collisions in the range 1.5 to 2.5 BeV. (L) *Phys. Rev. Letters* **11**, 474-6 (1963).

TURKOT, F., COLLINS, G.B., FUJII, T., KEMP, M.A.R., MENES, J., OOSTENS, J., CARRIGAN, R.A., EDELSTEIN, R.M., AND HIEN, N.C. Deuteron production in *p-p* collisions in the range 1.5 to 2.5 GeV. *Proc. Intern. Conf. Elementary Particles, Sienna, Italy, Oct. 1963* (in press).

ULRICH, B.T. – See JENKINS, E.W.

UNNA, I. AND WENESER, J. Corrections to the random phase approximation. (A) *Bull. Am. Phys. Soc.* **9**, 387 (1964).

VAN DEN HENDE, J.H. AND BOUTIN, H. The crystal structure of ferroelectric lithium hydrazinium sulfate. *Acta Cryst.* **17**, 660-3 (1964).

VAN DER LANS, J. Track center circuit for BNL HPD Mark I. Informal Report BNL 7681.

VINEYARD, G.H. – See ERGINSOY, C.; SHIMIZU, A.

VISE, J.B. AND RUSTAD, B.M. The electron-neutrino angular correlation in the decay of He^{6+}. *Phys. Rev.* **132**, 2573-81 (1963).

WAGENBLAST, H., FUJITA, F.E., AND DAMASK, A.C. Kinetics of carbon precipitation in irradiated iron. IV. Electron microscope observations. *Acta Met.* **12**, 347-53 (1964).

WAGNER, P. – See WARBURTON, E.K.

WARBURTON, E.K., ALBURGER, D.E., GALLMAN, A., WAGNER, P., AND CHASE, L.F. Determination of the multipolarity of nuclear electromagnetic transitions using a magnetic pair spectrometer. *Phys. Rev.* 133, B42-62 (1964).

WARBURTON, E.K., ALBURGER, D.E., AND WILKINSON, D.H. Magnetic pair spectrometer studies of electromagnetic transitions in Be^{10} and B^{10}. *Phys. Rev.* 132, 776-89 (1963).

WARBURTON, E.K. AND CHASE, L.F. Lifetime and spin-parity of the first excited state of B^{12}. *Phys. Rev.* 132, 2273-7 (1963).

WARBURTON, E.K., OLNESS, J.W., ALBURGER, D.E., BREDIN, D.J., AND CHASE, L.F. Studies of electromagnetic transitions in N^{14} by means of the $C^{12}(He^3,p)N^{14}$ reaction. *Phys. Rev.* 134, B338-48 (1964).

WARBURTON, E.K. – See also ALBURGER, D.E.; BECKER, J.A.; BREDIN, D.J.; DONOVAN, P.F. (Chemistry).

WEBRE, N.W. – See BURD, D.; STRAND, R.C.

WEBSTER, M.S. – See BALTAY, C.; BARNES, V.E.; GOZ, B.; HORWITZ, N.; SKILLICORN, I.O.

WEGNER, H.E. – See GIBSON, W.M. (Chemistry); RICKEY, M.E.

WENESER, J. – See CHURCH, E.L.; UNNA, I.

WESTGARD, J.B. – See BACON, T.C.

WHITE, M.B. – See COHEN, V.W.

WICK, G.C. – See TRUEMAN, T.L.

WILKINSON, D.H. – See ALBURGER, D.E.; BECKER, J.A.; WARBURTON, E.K.

WILL, G., FRAZER, B.C., SHIRANE, G., COX, D.E., AND BROWN, P.J. The cycloidal spin configuration of orthorhombic $MnSO_4$. (A) Presented at Am. Crystallographic Assoc. Meeting, Bozeman, Mont., July 1964.

WILL, G., NATHANS, R., AND ALPERIN, H.A. Neutron diffraction investigation of a gadolinium single crystal. *J. Appl. Phys.* 35, 1045-6 (1964).

WILL, G., PICKART, S.J., ALPERIN, H., AND NATHANS, R. Antiferromagnetic structure of EuTe. *J. Phys. Chem. Solids* 24, 1679-81 (1963).

WILLEN, E.H. – See FOLEY, K.J.

WILLIS, W.J. Charge independent K-n interactions – θ_2^0-p experiment. Informal Report BNL 8100.

WILLIS, W.J. Error matrix for bubble chamber track measurements. Informal Report BNL 7932.

WILLIS, W.J. K_2^0 test run scan. Informal Report BNL 8101.

WILLIS, W.J. Structure of the K-meson decay interaction. In *Proc. Intern. Conf. Fundamental Aspects of Weak Interactions, Brookhaven National Laboratory, Sept. 1963*, pp. 18-30, BNL 837 (C-39), April 1964.

WILLIS, W.J. TRED optical constants. Informal Report BNL 8102.

WILLIS, W.J. – See also BALTAY, C.; BARNES, V.E.; BURNSTEIN, R.A.; CONNOLLY, P.L.; COURANT, H.; FERBEL, T.; HART, E.L.; LUERS, D.

WOLFE, R. – See BARNES, V.E.

WRIGHT, D.H. General operation and construction features of the undercarriage system for the 80-in. bubble chamber. Informal Report BNL 7498.

YAMADA, R. – See FOLEY, K.J.

YAMAMOTO, S.S. Final coat-hanger design. Informal Report BNL 7489.

YAMAMOTO, S.S., BERTANZA, L., MONETI, G.C., RAHM, D.C., AND SKILLICORN, I.O. Production of strange particles by 2.77-BeV/c π^+ mesons on hydrogen. *Phys. Rev.* 134, B383-7 (1964).

YAMAMOTO, S.S. – See also BARNES, V.E.; CONNOLLY, P.L.; HART, E.L.; LAI, K.W.; LICHTMAN, S.; LLOYD, J.L.; LONDON, G.W.; LUERS, D.

YAO, T. A model for the interaction $p+p \rightarrow d+\pi^+$ in the BeV region. *Phys. Rev.* 134, B454-9 (1964).

YAO, T. – See also TRUEMAN, T.L.

YOUNG, C.G. – See GAMBLE, F.T.

YUAN, L.C.L. Future trends in detection techniques at super high energies. In *Proc. Intern. Conf. High Energy Accelerators, Dubna, USSR, Aug. 1963*, pp. 32-9, A.A. Kolomensky et al., Editors, Atomizdat, Moscow, 1964.

YUAN, L.C.L. Recent studies on the experimental program requirements for a super high energy accelerator. *Proc. Intern. Conf. High Energy Physics, Dubna, USSR, Aug. 1964* (in press).

YUAN, L.C.L. – See also FOLEY, K.J.; MILLER, G.L. (Instr. & Health Physics).

ZORN, B.S. – See BURNSTEIN, R.A.; COURANT, H.

ZUPANCIC, C. – See DONOVAN, P.F. (Chemistry).

Photography and Graphic Arts Division

GARFIELD, J. The photogrammetry of the tracks of elementary particles in bubble chambers. *Photogrammetria* (in press).

Reactor Division

ALLENSPACH, F.R. Control-rod calibration using an analog computer. (A) *Trans. Am. Nucl. Soc.* 6 *Suppl.*, 8-9 (1963).

THOMPSON, D. Broken blocks in the Brookhaven Graphite Research Reactor: A graphite-growth problem. (A) *Trans. Am. Nucl. Soc.* 6 *Suppl.*, 40-1 (1963).

THOMPSON, D. *Reactor Operations Monthly Reports* (For Official Use Only):

July 1963	BNL 817 (T-316)
Aug. 1963	BNL 822 (T-320)
Sept. 1963	BNL 826 (T-321)
Oct. 1963	BNL 830 (T-324)
Nov. 1963	BNL 835 (T-328)
Dec. 1963	BNL 840 (T-330)
Jan. 1964	BNL 843 (T-331)
Feb. 1964	BNL 849 (T-335)
Mar. 1964	BNL 858 (T-342)
Apr. 1964	BNL 862 (T-345)
May 1964	BNL 868 (T-348)
June 1964	BNL 872 (T-351)

Appendix B

OFFICERS AND SCIENTIFIC AND PROFESSIONAL STAFF

Maurice Goldhaber, *Director*
Clarke Williams, *Deputy Director*
Charles E. Falk, *Associate Director*
R. Christian Anderson, *Assistant Director*
G. Norris Glasoe, *Assistant Director*
Samuel M. Tucker, *Assistant Director*

G. Kenneth Green, *Chairman*, Accelerator Department
John W. Calkin, *Chairman*, Applied Mathematics Department
Howard J. Curtis, *Chairman*, Biology Department
Richard W. Dodson, *Chairman*, Chemistry Department
Horner Kuper, *Chairman*, Instrumentation and Health Physics Department
Victor P. Bond, *Chairman*, Medical Department
Warren E. Winsche, *Chairman*, Nuclear Engineering Department
George H. Vineyard, *Chairman*, Physics Department
Irving J. Polk, *Head*, Mechanical Engineering Division
Robert W. Powell, *Head*, Reactor Division

J. Georges Peter, *Director*, Architectural Planning
H. Russell Cort, *Budget Officer*
William J. Catacosinos, *Business Manager*
Lewis R. Burchill, *Controller*
Dennis Puleston, *Information Officer*
Charles F. Dunbar, *Legal Counsel*
N. Peter Rathvon, Jr., *Associate Counsel*
Joseph S. Washburne, *Personnel Manager*
Edward J. Burke, *Security Officer*

Accelerator Department

G. Kenneth Green, *Chairman*
Roger R. Adams
John C. Alderman
Lamar T. Baker
David A. Barge
Mark Q. Barton
Gerald W. Bennett
David Berley
Richard A. Beth
John W. Bittner
John P. Blewett
M. Hildred Blewett
Hugh N. Brown
Theodore Carides
Richard L. Cassel
William T. Chu
(postdoctoral appointment)
James G. Cottingham
Ray R. Crittenden*
Joseph A. Curtiss
Per Fridtjof Dahl
Gordon T. Danby
Donald A. Davis
Bernard L.C. de Sereville*
(assigned from Commissariat à l'Énergie Atomique, Saclay, France)
Edward W. Dexter
Henry M. Doupe
Emory G. Egler
Arthur J. Enright
Arnold V. Feltman
Theodore Fishman
Eric B. Forsyth
Robert S. Frankel
William R. Friskin
John J. Gabusi
William Gefers
Salvatore T. Giordano
Joseph W. Glenn, III
Allen S. Grossman
Harald Hahn
Henry J. Halama
John L. Harris
William E. Harrison, Jr.
Elias H. Hochman*
Robert S. Hulliger
John W. Jackson
Kurt Jellett
Henry Kasha
Ralph R. Kassner
John T. Keane
Robert A. Larson
Lawrence B. Leipuner
Gerald S. Levine
Su Tang Lin
Isador J. Livant
Walter Livant
Robert E. Lockey
Anthony J. Longano
Robert A. Loper
Edward A. MacDougall
Alfred W. Maschke

*Terminated before July 1, 1964.

Lowell McLean
Christoffel H. Meijer
Walter W. Merkle
William Michaelson
William H. Moore
Gerry H. Morgan
Albert C. Nerenberg
Tetsuji Nishikawa
(on leave from Univ. of Tokyo, Japan)
Eileen C. O'Donnell
Leslie W. Oleksiuk
Richard J. Orgass*
Arthur N. Otis, Jr.
George Parzen
Jean-Louis Pellegrin
Martin Plotkin
Eugene C. Raka
Leo H. Redmond, Jr.*
Raymond H. Rheaume
André Roussett
(on leave from École Nationale Supérieure des Mines de Paris, France)
Everett J. Rutan
Eleftherios J. Sacharidis
William B. Sampson
James R. Sanford
Albert J. Schoenemann
Mykola Sereda
Harold R. Shaylor
(on leave from Univ. of Birmingham, England)
Edward E. Shelton
Theodorus J.M. Sluyters
Lyle W. Smith
Anastasios Soukas
Julius Spiro
Colin D. Stewart
Robert C. Talsma
Bernard Thevenet
(on leave from Commissariat à l'Énergie Atomique, Saclay, France)
Arthur Tranis
Clarence M. Turner
Arie van Steenbergen
Robert J. Warkentien
Arnold R. Watts
Theodore F. Zipf

Applied Mathematics Department

John W. Calkin, *Chairman*
John A. Altson
Barry S. Arbeit
Susan M. Arnio
Elliott H. Auerbach
Lydia Bargiuk
William J. Beard*
David R. Beaucage
William Bouris*

*Terminated before July 1, 1964.

John R. Cannon
John E. Denes
Jerry M. Friedman
Kurt Fuchel
Evelyn Gottesfeld
John H. Halton
Sidney Heller
Stanley Kaplan
Arlene S. Larsen*
Leslie L. Lawrence
Alvin A. Legerlotz
Joel H. Malament
Robert B. Marr
John P. Milazzo
Noboru Nakanishi
Irene R. Nicodemus
Larry S. Padwa
Ilse Perlman*
Joel D. Pincus
Marc Platt
George Rabinowitz
Dysart A. Ravenhall
Reine M. Reele
Nechemiah Reiss
(on leave to Weizmann Inst. of Science, Rehovoth, Israel)
Stuart S. Rideout
Carole J. Sawner
Yoshio Shimamoto
Morris Skibinsky
Jacqueline J. Sluzka
Sebastian A. Sora
Morris M. Strongson
Bette E. Sullivan*
Roger N. van Norton
Betty Weneser
Annette L. Woodbury
Lourdes Zavitsas

Biology Department

Howard J. Curtis, *Chairman*
Jean Aitchison*
Nicholas Alonzo
Marvin R. Alvarez
(postdoctoral appointment)
Etsuo Amano
Donald G. Baker
Barbara G. Barnes
(assigned from U.S. Public Health Service; deceased January 22, 1964)
Brother Conrad William Batt
(assigned from Manhattan College)
Frederick R. Becherer
(on leave of absence)
Arnold M. Becker
John Berech, Jr.*
John A. Bergeron
Chittranjan Bhatia
(postdoctoral appointment)
Clara A. Bjerknes
Frederick H. Bormann
(on leave from Dartmouth College)
Francesco Bresciani*
(on leave from Univ. of Naples, Italy)
Robert W. Briggs
(postdoctoral appointment)
John R. Broich
Robert P. Carty
(postdoctoral appointment)
Nicholas C. Combatti
Gerard M. Courtin
D. Roy Davies*
(on leave from United Kingdom Atomic Energy Authority, Harwell, England)
Milislav Demerec
Basilio Donini*
(on leave from Univ. of Rome, Italy)
Grace M. Donnelly
(postdoctoral appointment)
Winston R. Dykeman
Julius M. Elias*
Frieda M. Englberger
William R. Evans*
(postdoctoral appointment)
Daniel S. Fackre
Theresa F. Ferrerio
David L. Filmer
Masaki Furuya
Walter J. Geisbusch
Om K. Ghei
(postdoctoral appointment)
Anne D. Gounaris
(postdoctoral appointment)
Lewis J. Greene
Eleanor Grist
Kenneth L. Grist
Elmer B. Hadley
(postdoctoral appointment)
Robert E. Heiner
(postdoctoral appointment)
William S. Hillman
C.H.W. Hirs
David G. Hoare
(postdoctoral appointment)
William G. Hopkins
(postdoctoral appointment)
H. Robert Horton
(postdoctoral appointment)
James R. Innes*
Alexandra H. Jahn
Leela M. Joshi
Yashwant Karkhanis*
(postdoctoral appointment)
J. Raymond Klein
Donald Koenig
Daniel E. Koshland, Jr.
Marian E. Koshland
Cirel H. Kroll*
Charles C. Kuehnert
(postdoctoral appointment)
Sanford A. Lacks

H. George Latham, Jr.
Harvard Lyman*
(on leave from Brooklyn College)
Timothy G. Marples
(postdoctoral appointment)
Alexander Micke*
(on leave from Univ. of Göttingen, West Germany)
Richard B. Middleton
(postdoctoral appointment)
Jerome P. Miksche
Morton W. Miller
(postdoctoral appointment)
Grace H. Moffat
(graduate student from New York Univ.)
Samuel M. Mozersky*
(assigned from National Inst. of Health)
Archie Murdock
(postdoctoral appointment)
Karen New
Leslie F. Nims
John M. Olson
Jan K. Oosting
Mary E. Owen*
(postdoctoral appointment)
Carmie A. Perrotta
(assigned from Yale Univ.)
Bernard Pivo*
Virginia Pond
Herbert Posner
(postdoctoral appointment)
Wolf Prensky*
(postdoctoral appointment)
Henry Quastler
(deceased July 4, 1963)
Allen Rebuck
Meir Rigbi
(on leave from Hebrew Univ., Jerusalem, Israel)
Nicholas Rigopoulos*
Francis G. Roskosky
John J. Ruscica
Kenneth E. Sanderson
(postdoctoral appointment)
Lloyd A. Schairer
Ursula Schnappauf
Janet S.D. Scott*
(postdoctoral appointment)
Kenneth Scott*
(postdoctoral appointment)
Donald L. Shaver
(assigned from National Inst. of Health)
Mogens R. Skougaard
(on leave from Royal Dental College, Copenhagen, Denmark)
Robert M. Smillie*
Harold H. Smith
Arnold H. Sparrow
Elizabeth Stanton
Robert Steele

*Terminated before July 1, 1964.

Mituru Takanami*
(on leave from Hiroshima Univ., Japan)
Keith H. Thompson
John J. Tilley, Jr.
Philomena C. Timmons
Jack van't Hof
Richard H. Wagner
(postdoctoral appointment)
Henry Weiner
(postdoctoral appointment)
Marilyn F. Wolfsberg
(assigned from National Inst. of Health)
Robert G. Woodley
George M. Woodwell
Ruth V. Wright
John C. Wriston, Jr.
(on leave from Univ. of Delaware)
Yonhan Yan
Arthur Zeitlin
Geoffrey Zubay*

Chemistry Department

Richard W. Dodson, *Chairman*
Hans-Joachim Ache
(postdoctoral appointment)
Augustine O. Allen
Alan Appleby
(postdoctoral appointment)
Elizabeth W. Baker
Werner H. Baur*
(on leave from Univ. of Göttingen, West Germany)
Benon H. Bielski
Jacob Bigeleisen
Raymond J. Campion*
(postdoctoral appointment)
Hai Won Chang
(postdoctoral appointment)
Joseph C.Y. Chen
David R. Christman
Yung Yee Chu
James C. Cobb
Kenneth E. Collins*
(postdoctoral appointment)
Teresa J. Conocchioli
Lester M. Corliss
James B. Cumming
Eileen P. D'Arcy
Raymond Davis, Jr.
Bodo Diehn*
(graduate student from Univ. of Kansas)
Paul F. Donovan
(assigned from Bell Telephone Laboratories, Inc.)
Israel Dostrovsky
(on leave from Weizmann Inst. of Science, Rehovoth, Israel)
Guenther Dulz*
(postdoctoral appointment)
Florence T. Dunne
Stanton Ehrenson
Norman Elliott
Fraser Fanale
(postdoctoral appointment)
Gian P. Felcher
(postdoctoral appointment)
Eena-Mai Franz
Simon Freed
John J. Freeman
(postdoctoral appointment)
Gerhart Friedlander
Lewis Friedman
Janusz M. Gebicki
Raymond Goldberg*
George A. Gregoriou*
(postdoctoral appointment)
James R. Grover
Walter C. Hamilton
Garman Harbottle
Julius M. Hastings
Karl H. Heinzinger
(postdoctoral appointment)
Shiu Kwong Ho
(postdoctoral appointment)
Jerome Hudis
Andries Hummel
(on leave from Ministry of Education, Arts, and Sciences, The Hague, Netherlands)
James A. Ibers
Adolph P. Irsa
Takanobu Ishida
(postdoctoral appointment)
Karin Karlstrom
(assigned from Columbia Univ.)
Seymour Katcoff
John D. Kelley
(postdoctoral appointment)
Ann M. Kistner*
(assigned from Columbia Univ.)
Fritz S. Klein*
(on leave from Weizmann Inst. of Science, Rehovoth, Israel)
Walter Kunnmann
Sam J. LaPlaca
Anne M. Lautzenheiser
Pak Sang Leung
(graduate student from Columbia Univ.)
Peter Lieberman
(graduate student from Brooklyn College)
George H. Megrue
(postdoctoral appointment)
Sandro Meloni*
(on leave from Univ. of Pavia, Italy)
James P. Mollenauer*
Thomas F. Moran
(postdoctoral appointment)
George H. Nancollas*
(on leave from Univ. of Glasgow, Scotland)
Beverly J. Nine
A. Edward Norris
(postdoctoral appointment)
Elinor F. Norton
Lars Borje Ostman
(postdoctoral appointment)

Catherine T. Paul
Morris L. Perlman
Norbert T. Porile
Arthur M. Poskanzer
Neil Purdie*
(postdoctoral appointment)
Birgit M. Rabe
Johann G. Rabe
(NATO Fellow)
Srinivasan Raman
(postdoctoral appointment)
Carol S. Redvanly
Paul L. Reeder
(postdoctoral appointment)
Louis P. Remsberg, Jr.
J. Keith Rowley
William Rubinson
Edward V. Sayre
Oliver A. Schaeffer
Harold A. Schwarz
William A. Seddon
(postdoctoral appointment)
Stanley Seltzer
Kohji Shimaoka
(postdoctoral appointment)
Frederick J. Silkworth, Jr.
Morris Slavin
Gerhard Stöcklin
(postdoctoral appointment)
Raymond W. Stoenner
Norman Sutin
Shigeo Tanaka*
(on leave from Univ. of Tokyo, Japan)
Sydney O. Thompson
Richard B. Timmons
(postdoctoral appointment)
Reginald M. Walters
(postdoctoral appointment)
Jesse M. Wampler
(postdoctoral appointment)
Freddie H. Watson, Jr.
Ralph E. Weston, Jr.
Alfred V. Willi
(on leave from Univ. of Bern, Switzerland)
Ronald Withnell
Alfred P. Wolf
Max Wolfsberg
Tucker T. Yee
(graduate student from Univ. of Massachusetts)
Ursula Zahn
(assigned from Univ. of Munich, West Germany)
Andreas A. Zavitsas
(postdoctoral appointment)

Instrumentation and Health Physics Department

Horner Kuper, *Chairman*
Abraham Arnold
Frank R. Berry*

*Terminated before July 1, 1964.

Robert M. Brown
Robert J. Champagne
Robert L. Chase
David O. Clark
Lester A. Cohen
Jerome Constant
Frederick P. Cowan
Carl H. Distenfeld
Jack C. Faust*
Joachim Fischer
Charles W. Flood, Jr.
Charles F. Foelix
John A. Frizzola
Lee Gemmell
William J. Hartin
William A. Higinbotham
Andrew P. Hull
John F. Jacobs
Robert J. King*
Peter S. Littlefield
(on military leave of absence)
Jorge Llacer
Robert O. McClintock
Charles B. Meinhold
Constance M. Nagle
Anthony Nappi
Casimir Z. Nawrocki
Michael J. O'Brien
David Ophir
(on leave from Israel Inst. of Technology, Haifa, Israel)
James P. Palmer
Howard R. Pate
Smith G. Pearsall
Leigh F. Phillips
David W. Potter
Veljko Radeka
(postdoctoral appointment)
Seymour Rankowitz
Gilbert S. Raynor
Edwin J. Rogers
Martin J. Rosenblum
(on leave to CERN, Geneva, Switzerland)
George E. Schwender
Stanley I. Silverman
Irving A. Singer
Maynard E. Smith
Robert J. Spinrad
Raymond W. Stong
Luis Tepper*
(on leave from Atomic Energy Commission, Tel-Aviv, Israel)
Sanford E. Wagner
Gaylord N. Wall
John B.S. Waugh*
Stanley Wood
Anthony H. Yonda, Jr.

Mechanical Engineering Division

Irving J. Polk, *Head*
Richard W. Aichroth
Richard C. Albert
Joseph E. Allinger
John G. Androulakis*
Robert D. Baldwin, Jr.
Joseph A. Bamberger
Alden J. Banslaben
Paul Bezler
Thomas J. Blair
Donald P. Brown
Robert H. Browne
Vernon J. Buchanan
Leonard N. Chimienti
Henry O. Courtney
Rudolph Damm
Jack E. Detweiler
Basil De Vito
Julius J. Diener
Carlo Ferraro, Jr.
Carl R. Flatau
Edward H. Foster
Donald W. Gardner
Robert J. Gibbs
Eugene O. Glittenberg
Jules B. Godel
Carl L. Goodzeit
Charles L. Gould
Philip E. Greenberg
John J. Gries
Melvin E. Griffing
John J. Grisoli
Eugene E. Halik
Charles R. Hedberg
John J. Hennessy
Rudolph S. Hodor
Kenneth C. Hoffman
John N. Hopping, Jr.
Hendrik Houtsager
Hank C.H. Hsieh
Donald W. Huszagh
Jack E. Jensen
Michael B. Karelitz
(deceased November 4, 1963)
David A. Kassner
Andrew Kevey
John T. Koehler
Calman Lasky
Boris M. Lomonosoff
Joseph Lypecky
Stanley J. Majeski
Paul Mandel
John G. Marinuzzi
Robert J. McCracken
Anthony P. Meade
Kurt F. Minati
Shih Chia Mo*
George Nugent
Joseph M. O'Donnell, Jr.
Adolph Oltmann
Frederick O. Pallas
Francis C. Pechar
Paul A. Pion
Carl J. Pozgay
Oliver S. Reading
Clive E. Reed

Morris Reich
Wesley G. Ripperger
Albert P. Schlafke, Jr.
Joseph C. Schuchman
Anthony Semplicino
Donald B. Sisson
John R. Sisson
Charles Theisen
Harvey J. Thomas
Reese D. Thomas
Helmuth Thorwarth
Vincent Troisi, Jr.
John C. Walker
William G. Walker
Irving J. Winters, Jr.
Henry H. Woelfel
Donald H. Wright

Medical Department

Victor P. Bond, *Chairman*
Vicente Alcober*
(on leave from Facultad de Medicina, Univ. de Valencia, Spain)
John O. Archambeau
Robert B. Aronson
Harold L. Atkins
John L. Bateman
(assigned from National Inst. of Health)
Donald C. Borg
Salvador R. Bozzo
(on leave from Univ. of Chile, Santiago)
Amos A. Britton*
(on leave from Univ. of Bogotá, Colombia)
Bernard J. Bryant
Arjun Dev Chanana
(on leave from District General Hospital, Bolton, England)
Donald H. Clifford*
(on leave from Univ. of Minnesota)
Stanton H. Cohn
Spencer L. Commerford
Robert A. Conard, Jr.
Constantinos Constantinides
Hans Cottier*
(on leave from Univ. of Bern, Switzerland)
George C. Cotzias
Eugene P. Cronkite
Lewis K. Dahl
Nicholas Delihas
Ruth M. Drew
Ralph G. Fairchild
Ludwig E. Feinendegen*
(assigned from EURATOM)
Theodor M. Fliedner*
Edith M. Forsyth*
Norman Z. Glatstein*
(on leave from Mt. Sinai Hospital, New York)
Ernest A. Gusmano
Leonard D. Hamilton
Lawrence V. Hankes

*Terminated before July 1, 1964.

Max W. Hess
Carl Hirsch
(graduate student from Univ. of Cincinnati)
Donald R. Huene
(assigned from U.S. Navy)
Walter L. Hughes*
Wen-Shui S. Hwang
John E. Jesseph
(on leave from Veterans Administration Hospital, Washington, D.C.)
Horton A. Johnson
Septimus M. Joubert*
(on leave from Univ. of Natal, Union of South Africa)
Hooney C. Kahng*
(medical associate)
Georg A. Keiser
(on leave from Univ. Hospital, Zurich, Switzerland)
Matina Kesse*
(on leave from Alexandra Hospital, Athens, Greece)
Louis C. Lax*
Robert A. Love
Nicholas Odartchenko*
Nobuyoshi Oji
(on leave from Osaka Univ. Medical School, Japan)
Paul S. Papavasiliou
Mildred Pavelec
Edwin A. Popenoe
Kedar N. Prasad
José Ramos
(on leave from Facultad de Medicina, Univ. de San Marcos, Lima, Peru)
Paul Reilly*
Luis Rizo-Patrón*
(on leave from Facultad de Medicina, Univ. de San Marcos, Lima, Peru)
James S. Robertson
Charles V. Robinson
Arthur Sakamoto
Eckart Schackow*
Lewis M. Schiffer
Hanspeter Schnappauf
(on leave from Justus Liebig Univ., Giessen, West Germany)
Stephen L. Schwartz
(graduate student from Univ. of Cincinnati)
Vinod C. Shah*
Walton W. Shreeve
Clyde R. Sipe
Richard D. Stoner
Pierre A. Stryckmans
(on leave from Inst. Jules Bordet, Brussels, Belgium)
Andrew J. Tashjian
(U.S. Public Health Service Fellow)
George M. Tisljar-Lentulis
Edgar A. Tonna
Donald D. Van Slyke
Adrianus A. van Soestbergen
Melvin H. Van Woert
Wallace M. Wass*
(on leave from Univ. of Minnesota)
Charles R. Young

Nuclear Engineering Department

Warren E. Winsche, *Chairman*
George Adler
Christopher Agritellis
Sidney J. Altschuler*
(graduate student from Columbia Univ.)
Eigil Andersen*
(assigned from Kjeller Research Establishment, Norway)
Arnold L. Aronson
Seymour Aronson
Clemens Auerbach
Allan Auskern
David S. Ballantine
Charles B. Bartlett
Morris Beller
William N. Bishop
Fritz Bloch
John S. Bookless
William Bornstein
Joseph S. Bryner
Carlos A. Cannistraci*
(assigned from Atomic Energy Commission, Buenos Aires, Argentina)
Albert W. Castleman, Jr.
M.S. Chandrasekharaiah*
(postdoctoral appointment)
Renate W. Chasman
John Chen
Jack Chernick
Chang S. Choi*
(assigned from Atomic Energy Research Inst., Seoul, Korea)
Joe G.Y. Chow
Evelyn A. Cisney*
John T. Clarke
Carol H. Collins*
(postdoctoral appointment)
Peter Colombo
Helen R. Connell
Noel R. Corngold
Anita J. Court
Russell N. Dietz
Robert F. Doering
Roy F. Dornish
Kenneth W. Downes
James M. Dwyer*
(postdoctoral appointment)
Orrington E. Dwyer
James J. Egan
Leonard C. Emma
Lester G. Epel
Seymour G. Epstein
Jack Fajer
(postdoctoral appointment)
Peter T. Fallon

Joan F. Felberbaum
Stephen W. Feldberg*
(postdoctoral appointment)
Harmon L. Finston*
Albert H. Fleitman
Markley H. Flom
Jack J. Fontana
Joseph Forrest
Bernard R. Fox
Leonard Galanter
John D. Garrison*
(on leave from San Diego State College)
Ajoy K. Ghatak
(postdoctoral appointment)
Althea Glines
Donald A. Goellner
Murrey D. Goldberg
Barry M. Gordon
Stephen K. Gordon*
Leon Green
Margaret W. Greene
David H. Gurinsky
Yuuki Hachiya*
(assigned from Nippon Electric Co., Ltd., Kawasaki, Japan)
John C. Hasson
(graduate student from Polytechnic Inst. of Brooklyn)
Loranus P. Hatch
Michael A. Helfant
Robert L. Hellens
Joseph M. Hendrie
Raymond J. Heus
Frank B. Hill
Manny Hillman
Peter J. Hlavac
Ting-Chang Ho
(graduate student from Polytechnic Inst. of Brooklyn)
Henry C. Honeck
Frederick L. Horn
Chia-Jung Hsu
(postdoctoral appointment)
Robert J. Isler
Stanley D. James
Richard Johnson
Stuart C. Jones
Sheldon Kalish
Otto F. Kammerer
Herbert M. Katz
John J. Kelsch
Richard L. Kiefer
(postdoctoral appointment)
Akiichi Kigoshi*
(assigned from Tohoku Univ., Sendai, Japan)
Mary T. Kinsley
George Kissel
Carl J. Klamut
Paul J. Klotz

*Terminated before July 1, 1964.

Herbert J.C. Kouts
Henry Kramer
Theodore J. Krieger
Otto A. Kuhl
Lawrence E. Kukacka, Jr.
Maret Kukk
Fumio Kurosawa
(assigned from Nippon Electric Co., Ltd., Kawasaki, Japan)
Daniel F. Leahy
Dean T. Lee
(graduate student from Polytechnic Inst. of Brooklyn)
Gerald S. Lellouche
Melvin M. Levine
Stephen Lewkowitz
Dominic J. Macchia*
Donald R. MacKenzie
Benjamin Magurno
Bernard Manowitz
Michael W. Maresca
Victoria L. May
David K. McGuire
(postdoctoral appointment)
James J. McNicholas
S. Bradford McRickard
Donald J. Metz
Paul A. Michael
Julius Milau
Francis T. Miles
(on leave to IAEA, Vienna, Austria)
Jacobus G. Mohr
(graduate student from New York Univ.)
Sophie O. Moore
Albert C. Muller
Kunihiko Nakamura
Leonard Newman
Bruce Nimmo
Philip F. Palmedo
Guyon P. Pancer
Raymond J. Parsick
Arthur Paskin
Sol Pearlstein
John H. Petropoulos*
(on leave from Nuclear Research Center, Athens, Greece)
James P. Phelps
Charles E. Porter, Jr.
James R. Powell, Jr.
Richard M. Powers
Thomas F. Prach
Glenn A. Price
Jacob Pruzansky
Bernard C. Quiquemella
(on leave from EURATOM)
Hanumantha M. Rao
(assigned from Atomic Energy Establishment, Bombay, India)
Chad J. Raseman
James J. Reilly, Jr.
Powell Richards

Francis X. Rizzo
Anthony Romano
Michael A. Rothbart
Jerome Sadofsky
Francis J. Salzano
Sergio Santiago-Paez*
(assigned from Junta de Energía Nuclear, Madrid, Spain)
César A. Sastre
Clifford H. Scarlett
Donald G. Schweitzer
Alfred Seguel-Moas
(on leave from Catholic Univ. of Santiago, Chile)
Balraj Sehgal
Charles S. Shapiro*
(graduate student from Syracuse Univ.)
Thomas V. Sheehan
Louis M. Shotkin
(postdoctoral appointment)
Richard S. Siegel*
(on leave from Bronx High School of Science)
Robert M. Singer
Louis M. Slater
John L. Speirs
Govindasharama Srikantiah
(postdoctoral appointment)
Louis G. Stang, Jr.
John R. Stehn
Meyer Steinberg
Gerald Strickland
Herbert Susskind
James W. Sutherland
Ignatius Ning-Bang Tang
Yau C. Tang
(postdoctoral appointment)
Silvio J. Tassinari
Paul R. Tichler
Richard J. Tivers
Elmer M. Tory
Walter D. Tucker
William J. Tunney
Edwin J. Tuthill
James O. Tveekrem
Nazakat Ullah*
(postdoctoral appointment)
John D. Van Norman
Stephen J. Wachtel
Jean I. Wagner
Charles H. Waide
John R. Weeks
Eugene V. Weinstock
Allen J. Weiss
Jerome Weiss
George G. Weth
Michael M.R. Williams*
(postdoctoral appointment)
Robert G. Wilson
Virginia H. Wilson
Henry H. Windsor
Edward Wirsing, Jr.
Richard H. Wiswall, Jr.

Wen-Shi Yu*
(graduate student from Polytechnic Inst. of Brooklyn)
Martin S. Zucker

Physics Department

George H. Vineyard, *Chairman*
Fernando Agullo-López*
(on leave from Junta de Energía Nuclear, Madrid, Spain)
Ian J.R. Aitchison*
(postdoctoral appointment)
David E. Alburger
Harvey A. Alperin
(assigned from U.S. Naval Ordnance Laboratory)
Richard Arndt
Frederick Ayer, II*
Trevor C. Bacon
(postdoctoral appointment)
Charles P. Baker
Winslow F. Baker
(on leave of absence)
Virgil E. Barnes
(postdoctoral appointment)
George E. Barr*
(graduate student from Oregon State Univ.)
John A. Becker
(postdoctoral appointment)
Lewis I. Berlent*
Brother Austin Bernabei*
(grauate student from New York Univ.)
Mulki R. Bhat*
(postdoctoral appointment)
Edward J. Bleser
(postdoctoral appointment)
Martin Blume
Dermot J. Bredin*
Gunter Brunhart
Yau W. Chan
(postdoctoral appointment)
Chellis Chasman
Robert E. Chrien
Eugene L. Church
(assigned from Frankford Arsenal)
J.J. Anselm Citron
(assigned from CERN, Geneva, Switzerland)
Colin D. Clark
(on leave from Reading Univ., England)
Jack A. Cockrill
Victor W. Cohen
Isaac W. Cole
George B. Collins
Philip L. Connolly
Philip I. Connors
(graduate student from Pennsylvania State Univ.)
Rodney L. Cool
William N. Cottingham
(postdoctoral appointment)

*Terminated before July 1, 1964.

Ernest D. Courant
David E. Cox
Paul P. Craig
David J. Crennell
(postdoctoral appointment)
Bernard B. Culwick
Stephen A. Cutler
Arthur C. Damask
(assigned from Frankford Arsenal)
Horace R. Danner*
William C. Delaney
Mary A. Derengowski
(graduate student from Columbia Univ.)
Edward der Mateosian
George J. Dienes.
Jean V. Domish
Richard M. Edelstein
(assigned from Carnegie Inst. of Technology)
Frederick R. Eisler
Guy T. Emory
Cavid Erginsoy
Horst W. J. Foelsche
(graduate student from Yale Univ.)
Kenneth J. Foley
Hugie L. Foote, Jr.
William B. Fowler
Joan F. Franz*
Paola Franzini
B. Chalmers Frazer
Joseph L. Friedes
(postdoctoral appointment)
Tadao Fujii
William Galbraith
(on leave from United Kingdom Atomic Energy Authority, Harwell, England)
Robert S. Gilmore
(assigned from National Inst. for Research in Nuclear Science, Harwell, England)
Eli Glazer
Allen N. Goland
Malcolm Goldberg
Gertrude S. Goldhaber
Julio A. Gonzalo*
(assigned from Puerto Rico Nuclear Center)
Samuel A. Goudsmit
Michael G. Gundzik
(graduate student from Syracuse Univ.)
Patrick Hagerty
(graduate student from Syracuse Univ.)
Edward L. Hart
Arthur Herschman
(assigned from The Physical Review)
Benjamin H. Hertzendorf
Nguyen C. Hien
(assigned from Carnegie Inst. of Technology)
Virgil L. Highland
(assigned from Cornell Univ.)
William J. Hilger
(on military leave of absence)

David A. Hill
(assigned from Massachusetts Inst. of Technology)
David G. Hill
(postdoctoral appointment)
Akio Honma
(on leave from Tokyo Univ. of Education, Japan)
Henry W.K. Hopkins
(postdoctoral appointment)
John Hornbostel
Paul V.C. Hough
James J. Hurst, Jr.
Hidetsugu Ikegami
(on leave from Tokyo Univ., Japan)
Adeshwar P. Jain*
(postdoctoral appointment)
Edgar W. Jenkins
Robert A. Johnson
(postdoctoral appointment)
Keith W. Jones
Roger S. Jones
Jovan V. Jovanovic*
(postdoctoral appointment)
Siegfried Kalbitzer
(postdoctoral appointment)
Walter R. Kane
Paul B. Kantor
(postdoctoral appointment)
David T. Keating
Stuart H. Kern
Ottmar C. Kistner
Joshua K. Kopp
Saul Krasner
(assigned from Picatinny Arsenal)
Tzee-Ke Kuo
(postdoctoral appointment)
Thaddeus F. Kycia
Kwan Wu Lai
(postdoctoral appointment)
Ronald E. Larsen*
(assigned from Frankford Arsenal)
Boran A. Leontic
Frank S. Levin
(postdoctoral appointment)
Paul W. Levy
Kelvin K.Y. Li
(graduate student from Massachusetts Inst. of Technology)
Seymour J. Lindenbaum
Max Lipsicas
Demetrios T. Liverios*
John L. Lloyd
(postdoctoral appointment)
Andrew M. Lockett, III
(assigned from Los Alamos Scientific Laboratory)
Georges W. London
(graduate student from Univ. of Rochester)
Robert I. Louttit
(on leave to Centre d'Études Nucléaires, Saclay, France)
William A. Love

Eugene R. Marshalek
(postdoctoral appointment)
Clyde L. McClelland
(on leave to Arms Control and Disarmament Agency, Washington, D.C.)
Michael McKeown
Daniel McSweeney
John Mellor
(postdoctoral appointment)
Jack Menes
Sergio Monaro*
(postdoctoral appointment)
John A. Moore
Thomas I. Moran*
Thomas W. Morris
Bernard Mozer
Said F. Muchabghab
(postdoctoral appointment)
Vernon W. Meyers
(assigned from National Bureau of Standards)
Joseph A. Nardi, Jr.
Robert Nathans
John W. Olness
James J. O'Reilly
Yona Oren
(postdoctoral appointment)
Kare Otnes
Satoshi Ozaki
Harry Palevsky
Robert B. Palmer
Peter D. Parker
Laurence Passell
Ronald F. Peierls
Roger G. Perret
(postdoctoral appointment)
Jorgen S. Petersen*
(on leave from Atomic Energy Commission, Risö, Denmark)
Robert H. Phillips
Stanley J. Pickart
(assigned from U.S. Naval Ordnance Laboratory)
Louis K. Potter, Jr.
Albert G. Prodell
Dusan Radojicic
David C. Rahm
R. Ronald Rau
A. Lincoln Read
James T. Reed
(graduate student from Univ. of Rochester)
Clarence R. Richardson
Martin E. Rickey*
(on leave from Univ. of Colorado)
Kenneth F. Riley*
(postdoctoral appointment)

*Terminated before July 1, 1964.

Robert A. Ristinen*
(postdoctoral appointment)
Donald K. Robinson
Roy Rubenstein
(assigned from Cornell Univ.)
Henry Ruderman
(postdoctoral appointment)
John J. Russell, Jr.*
Brice M. Rustad
(assigned from Columbia Univ.)
Eileen Saffron*
Vance L. Sailor
Edward O. Salant
Nicholas P. Samios
Yoshiki Sato*
(on leave from Japan Atomic Energy Research Inst., Tokai-mura, Japan)
Robert I. Schermer
Janet C. Schnecke*
Ivan Schroder
(graduate student from Columbia Univ.)
Arthur Z. Schwarzchild
Romeo A. Segnan
(postdoctoral appointment)
Akinao Shimizu*
(assigned from Nippon Atomic Industry Group Co., Ltd., Tokyo, Japan)
Gen Shirane
Ralph P. Shutt
Henry B. Silsbee
(on leave from Univ. of Washington)
John R. Smith
(postdoctoral appointment)
Joseph E. Smith
John H. Sondericker
Robert L. Stearns
(on leave from Vassar College)
Morton M. Sternheim*
(postdoctoral appointment)
Rudolph Sternheimer
David L. Stonehill
Richard C. Strand
Elizabeth D. Stretch*
Myron Strongin
Robert Stump*
(on leave from Univ. of Kansas)
John Sunderland
(graduate student from Columbia Univ.)
Andrew W. Sunyar
Richard J. Sutter
Kasuke Takahashi
(postdoctoral appointment)
Michael J. Tannenbaum
(graduate student from Columbia Univ.)
William M. Thompson
Alan Thorndike
John R. Townsend*
(on leave from Univ. of Pittsburgh)

Peter D. Townsend
(assigned from Picatinny Arsenal)
George L. Trigg
(Editor of The Physical Review)
T. Laurence Trueman
(postdoctoral appointment)
Frank Turkot
William A. Tuttle
Issachar Unna
(postdoctoral appointment)
John H.M. Van Der Lans
Cesare F. Voci
(on leave from Univ. of Padua, Italy)
Robert L. Warasila
Ernest K. Warburton
Neil W. Webre*
Medford S. Webster
Harvey E. Wegner
David M. Weigand
Joseph Wenzer
Gian Carlo Wick
Erich H. Willen
(postdoctoral appointment)
William J. Willis
Ernest Windschauer
Estarose Wolfson
Chien-Shing Wu*
(on leave from Columbia Univ.)
Rjuji Yamada
(postdoctoral appointment)
Sukeyasu S. Yamamoto
Tsu Yao
(postdoctoral appointment)
Jean Yoccoz
(on leave from Univ. of Strasbourg, France)
Thomas J. Ypsilantis*
Luke C.L. Yuan
Martin S. Zucker
Charles A. Zuroff

Reactor Division

Robert W. Powell, *Head*
Frederick Allenspach
Paul Colsmann
George Demirjian
Francis A. Dugan
John J. Floyd
Gerald C. Kinne
Paul E. Mamola
Frederick J. Morse
(graduate student from Rensselaer Polytechnic Inst.)
Charles L. Osborne
Jack E. Phillips
dePuyster G. Pitcher
Seymour R. Protter
Walter H. Reed
Dudley Thompson