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Brookhaven Highlights

October 1978 September 1979

High Energy Physics

Physics and Chemistry

Life Sciences

Applied Energy Science

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Introduction

Brookhaven National Laboratory is operated by Associated Universities, Inc. (AUI) under a contract with the United States Department of Energy (DOE). The Laboratory conducts a broad range of basic and applied research programs in the physical and life sciences. It occupies a 21 km^2 tract of land at Upton, NY, approximately at the geographic center of Long Island, about 100 kilometers east of New York City.

AUI was formed in 1946 by a group of nine universities for the purpose of establishing and managing Brookhaven National Laboratory and other research centers. This action represented a new approach to the management of fundamental research with the support of the Federal government, especially for large-scale scientific enterprises of importance to the academic community.

From 1947 to 1975 the Laboratory was supported by the U. S. Atomic Energy Commission. In 1975 the Atomic Energy Commission was abolished, and most of its research programs were taken over by the Energy Research and Development Administration, which in 1977 was incorporated into the newly created Department of Energy. The U. S. Nuclear Regulatory Commission, which was formed in 1975 to take over the regulatory functions of the AEC, supports a continuing program of studies at Brookhaven on the safety of nuclear power reactors.

The primary objectives of the Laboratory are:

— To seek new scientific knowledge, with emphasis on programs that require large-scale research tools such as particle accelerators, nuclear reactors, and special laboratories that are beyond the scope of individual educational institutions.

— To encourage use of its facilities by scientists from universities, research institutions, and industry.

— To assist the Department of Energy in the performance of tasks that utilize the Laboratory's unique facilities and organization or the special talents of its staff.

— To serve as an important auxiliary in the training of scientists and engineers, and otherwise to assist in the dissemination of scientific and technical knowledge.

To fulfill the first and second of these objectives, the Laboratory has designed and built a series of large research devices. The first generation of these, the Cosmotron and the Brookhaven Graphite Research Reactor, have already completed long and useful programs of research and have been replaced by newer machines. Today the Alternating Gradient Synchrotron (AGS) accelerates protons to energies up to 30 GeV and continues as one of the nation's primary devices for high energy physics research. The High Flux Beam Reactor provides intense beams of neutrons for fundamental experiments in nuclear and solid state physics, chemistry, and biology. The Medical Research Reactor serves for activation analyses and for medical dosimetry studies. The Tandem van de Graaff installation provides beams of many varieties of ions at energies up to several hundred MeV for fundamental research in nuclear physics. Several smaller accelerators are also employed for solid state physics and nuclear research. A 60-inch cyclotron and the linac injector to the AGS produce many special isotopes, primarily for medical research and treatment. A scanning transmission electron microscope provides extremely high resolution for investigation of biological molecules and subcellular structures. A pulmonary toxicology facility allows the study of animals exposed to atmospheres of hazardous substances.

In each of these facilities a core of Brookhaven scientists and engineers performs research and oversees the maintenance and upgrading of the facility. Scientists from universities, other laboratories, and industry also use the facilities, sometimes in collaboration, and often independently. At many of the facilities the visitors outnumber the Brookhaven users substantially. At the AGS, for example, about 80% of the research is done by visitors.

In furtherance of this role of providing research machines, the Laboratory has under construction two new devices designed to meet de-

veloping needs of science: The ISABELLE colliding beam storage accelerator will provide intersecting beams of protons at energies up to 800 GeV in the center of mass system (equivalent to protons impinging on a fixed target with energy of 340 TeV). This machine will allow deeper studies into the nature of matter and the fundamental forces which hold it together. The National Synchrotron Light Source will provide intense beams of ultraviolet light and x-rays for experiments in physics, chemistry, the life sciences, and technology.

The third of the Laboratory's primary objectives has resulted in the formation of selected programs in energy technology and in various kinds of technical support to the Department of Energy. Included are programs to apply superconductivity to the transmission of large blocks of electric power; to develop intense sources of negative ions for heating plasmas for fusion; to develop a new method for the flash hydropyrolysis of coal; to develop better electrochemical systems for energy conversion and storage; and to develop solar-assisted heat pumps. Technical support to the DOE is provided by the National Center for Analysis of Energy Systems, which conducts a variety of national and regional studies on energy systems, their characteristics and their impacts on health; the Technical Support Office for Safeguards, which analyzes systems for preventing the diversion of fissionable materials to unauthorized uses; and the National Nuclear Data Center which assembles and disseminates data on the properties of atomic nuclei.

It should also be emphasized that the Laboratory's programs in nuclear, atomic, and solid state sciences, in chemistry, and in applied mathematics are designed to help create a technology base for the entire energy program of the DOE. These and the various applied programs build on the strengths and unique facilities of the Laboratory, utilizing its special character, particularly its devotion to frontier science, its close coupling to the academic community, and its experience in working with industry. The contributions are vigorous, broad, and effective.

The Laboratory's objective of training is accomplished primarily through the provision of research opportunities for students from colleges and universities. The Laboratory is not a degree-granting institution, but helps such institutions through its research facilities. Students and faculty come to the Laboratory throughout the year and particularly in the summer, not only to use the unique devices but as participants in all of the Laboratory's research programs. In addition, numerous conferences in science and technology are sponsored by Brookhaven. Developments of technological significance made at the Laboratory are expected to be passed on to industry for commercialization, and an increasing effort is being made to this end.

Several years ago, largely as an economy measure, the Laboratory stopped issuing an annual report and began publishing the HIGHLIGHTS on a biennial basis — the last issue covering the period July 1976 through September 1978. But when the inevitable lag in publication is added on it is obvious that much of the news value of the research reported has been lost. Accordingly we have decided to go back to annual publication, with this report covering Fiscal Year 1979 — October 1978 through September 1979.

Since the special facilities are best seen in terms of the research that is done with them, the arrangement of the last HIGHLIGHTS has been followed in which major additional facilities or improvements to existing ones are linked to the research program of the department that is the principal user. Thus ISABELLE is described in the High Energy Physics section, the National Synchrotron Light Source, due for completion in 1981, is described under the Solid State program of the Physics Department, and the Inhalation Toxicology Facility in connection with the Medical Department.

In the hope of making things easier for readers who wish to know more about particular items, references to selected published papers and staff lists with indication of individuals' particular interest have been appended. The comments of readers would be most welcome.

Finally, the editorial work of Dr. J. B. Horner Kuper on this report is gratefully acknowledged.

George H. Vineyard
Director

High Energy Physics

High Energy Physics Research

Accelerator Department

ISABELLE

Accelerator and High Energy Physics Programs

General Introduction

High energy physics is the largest program in the Laboratory budget. It might better be described as the particle physics research program. Using the Alternating Gradient Synchrotron (AGS) as a tool, teams of experimenters from BNL and from universities and laboratories located throughout the U.S. carry out experiments probing the ultimate structure of matter. The AGS accelerates protons (the nuclei of hydrogen atoms) to an energy of 30 billion electron volts (GeV) to provide projectiles for smashing the nucleus of other atoms. The enormous energy released in this collision scatters the primary protons and the constituents of the target nucleus and also results in the production of new unstable short lived particles not found in ordinary matter. The study of the scattering and production processes provides information about the constituents of the proton. The most fundamental of these now known are the "quarks." The quark model is part of a theory that has been very successful in explaining many of the observed properties of the proton and has provided a beautiful classification scheme for the many unstable particles.

ISABELLE, BNL's new high energy intersecting storage accelerator now under construction, will achieve collision energies over 100 times as great as that of the AGS. Many of the present puzzles in particle physics theory should be understood from the results of experiments using ISABELLE.

Proposals for experiments using the AGS must be submitted to the High Energy Advisory Committee composed of highly qualified physicists representative of the entire user community. This committee advises the Associate Director for High Energy Physics who must approve all experiments before they can be scheduled on the AGS. About 80% of the research is carried out by visiting scientists from universities, other National Laboratories, and occasionally from abroad.

The Accelerator Department operates the AGS and experimental areas. The Department provides the beams of protons, antiprotons, kaons, mesons, and neutrinos which are needed for the experiments. Department personnel assist the experimenters in setting up their apparatus and provide many services essential to carrying out the experiments. Large experimental facilities, such as the Multiparticle Spectrometer and the On-Line Data Facility, are constructed, operated, and maintained by the Department. Some of the Department physicists also participate in the experimental program.

The Physics Department is staffed with both experimentalists and theorists. The experimentalists are mainly involved with research at the AGS, but a small fraction of the effort is carried out at other accelerators. The theorists provide the stimulus of exciting new ideas in particle physics and devote much of their time to a continuing study of the results from the experiments using the AGS and the other high energy accelerators in the U.S. and Europe.

The High Energy Discussion Group (HEDG) is an organization brought into being by the community of university and National Laboratory users of the AGS "to provide an organized channel for the interchange of information between those who utilize BNL high energy facilities for their research and the Laboratory administration." HEDG holds one general meeting at BNL annually in the Spring. Much of the work of the users group is coordinated by the HEDG Executive Committee which meets three times a year.

High Energy Physics Research

INTRODUCTION

Before embarking on a discussion of the research in high energy physics at BNL in the past fiscal year, it may be helpful to give a brief outline of the modern theory of the nucleus as a framework for understanding the experimental program.

Since the discovery of the J or ψ particle simultaneously at BNL and at SLAC in 1974, there has been a revolution in high energy physics. It is now generally believed that there are only two classes of fundamental constituents of matter: leptons and quarks. Furthermore, all of the interactions among these constituents are described by gauge theories, that is, generalizations of electromagnetism. Thus, while many problems remain to be solved, we now have a unified theoretical picture of high energy physics. The following discussion is intended as a brief introduction to this picture.

Both leptons and quarks are spin ½ particles. The leptons are those which do not undergo strong interactions. Only the following (and their antiparticles) are believed to exist: the familiar electron (e), the muon (μ), the τ, recently discovered at SPEAR, and their respective neutrinos (ν_e, ν_μ, and ν_τ). The neutrinos have zero electric charge, so that they interact only weakly, and they have zero or very small masses. All known properties of the leptons are consistent with their having no internal structure, making them useful as probes of the structure of other particles.

Quarks are hypothetical objects; indeed, if present theoretical ideas are correct, they can never be produced as free particles. Nevertheless, we have good indirect evidence for them. All hadrons, or strongly interacting particles, are made up of various types, or "flavors," of quarks and their antiquarks. The three flavors which were known before the J/ψ was discovered are called u (up), d (down), and s (strange). Mesons, the hadrons with integer spin, are made from all possible combinations of a quark and an antiquark, while baryons, the hadrons with half integer spin, are made from three quarks. (Mesons and baryons made from more quarks have been suggested theoretically, but none has been established.) For this scheme to work, the quarks must be assigned spin ½, baryon number ⅓, and charges of ⅔ or −⅓. Then the known baryons fit into representations which are symmetric in the space and spin variables. Since the quarks have spin ½, they should have Fermi-Dirac statistics. It is therefore necessary to suppose that each quark flavor occurs in three distinct varieties with an exact SU(3) symmetry among them. These varieties are called "colors." Requiring the hadrons to be singlets under color gives the correct statistics. Color plays an important role in strong interactions.

The J/ψ was the first evidence for the existence of the c (charm) quark. Because it is so long-lived, it is interpreted as a $^3S_1$ bound state of $c\bar{c}$; such a state decays strongly but at a suppressed rate. Subsequently, experimenters at SLAC found $c\bar{c}$ radial excitations and P-wave states, and weakly decaying $c\bar{u}$ and $c\bar{d}$ mesons carrying non-zero charm. Indications of charmed baryons have been found in neutrino interactions at BNL. The significance of the discovery of charm was not just that a new quark flavor had been found. The study of the rich $c\bar{c}$ spectrum made it clear that quarks have real dynamical significance and are not just "bookkeeping" devices. Furthermore, the existence of charm and many of its properties had been predicted theoretically from gauge models of weak interactions, and the success of these predictions led to confidence in the entire picture. More recently, physicists at Fermilab discovered the Y, which is apparently the analog of the J/ψ for a fifth quark flavor.

Additional evidence for quarks comes from electron-proton (ep) and neutron-proton (np) scattering at large momentum transfer q. The elastic cross sections for these processes fall rapidly with increasing q, as one would expect for scattering on a large object. However, the inelastic cross sections behave as if the electron or neutrino scattered from a free, pointlike quark

within the proton, except that no quarks are produced. This requires that the force between quarks must be small at distances of order h/q, so that they appear to be free during the scattering, but strong at longer distances, so that they do not escape. The idea that a hadron can be treated as a collection of free constituents in large-momentum-transfer processes will be used below.

The strong, electromagnetic, and weak interactions of quarks and leptons are all believed to be described by gauge theories. Electromagnetism is an exact gauge theory, and it has long been known that quantum electrodynamics describes electrons and photons with great accuracy. In 1967 Weinberg and Salam suggested that weak and electromagnetic interactions could be combined in a larger gauge theory containing two charged weak bosons (W^+ and W^-), a neutral weak boson (Z^0), and the photon. To get the right strength for weak interactions, the gauge invariance cannot be exact but must be broken spontaneously,* causing the otherwise massless weak bosons to acquire masses of the order of 100 GeV/c^2. The spontaneous symmetry breaking preserves many desirable features of the unbroken theory, including in particular the ability to do systematic calculations to arbitrary accuracy.

In the Weinberg-Salam model the Z^0 couplings are strongly constrained by gauge invariance; with only three quarks they do not conserve strangeness, contradicting experimental results. In 1970, Glashow, Illioupoulis, and Maiani showed that the neutral current would conserve strangeness if a fourth quark, the charmed quark, with certain specific properties was introduced. The discovery of the J/ψ and the subsequent study of charmed particles has shown that this quark indeed exists and has just the right properties. The success of the prediction has led to confidence in the whole idea of gauge theories.

While many gauge theories have been proposed, within the last year the structure of all the weak currents has been determined experimentally and found to be in good agreement with the original Weinberg-Salam model with charm.

*A familiar example of spontaneous symmetry breaking is provided by magnetism. All of the interactions are invariant under rotations, but the ground state has a magnetic field pointing in a particular direction, thus breaking the rotational symmetry.

The argument for a gauge theory of strong interactions is based on the fact that the quarks within a hadron appear to be free at large momentum transfer. The only known field theories which could give such behavior are gauge theories based on unbroken, non-Abelian symmetries. Since the color symmetry of quarks is such a symmetry, the gauge theory of color is the natural candidate for the theory of strong interactions. This theory is called quantum chromodynamics, and its massless vector bosons are called gluons. At short distances it has essentially free quarks. Corrections to the free-quark predictions for ep and νp scattering can be calculated and improve the agreement with experiment. At long distances the massless gluons lead to strong and very complicated forces. It is hoped, although not proven, that these forces are so strong that they confine the quarks and gluons within hadrons, explaining why they are not seen as free particles.

OVERVIEW OF AGS EXPERIMENTS

The AGS experimental program is naturally divided into neutrino experiments and hadronic experiments. In neutrino experiments it is necessary to produce the maximum possible number of neutrinos, because their cross sections for interactions are so small. Therefore the entire proton beam is kicked out of the AGS and dumped onto a target, producing π and K mesons. These are focused magnetically and allowed to decay into neutrinos in a tunnel about 50 m long. A thick shield at the end of this tunnel absorbs all particles except the neutrinos, which pass through it to the detectors.

In hadronic experiments the proton beam is extracted slowly from the AGS and split among several users. A given experiment may use either the primary proton beam or, more commonly, one of several secondary beams. These are formed by directing the protons onto a target, focusing the produced particles magnetically and selecting those of the desired momentum, and transporting these through magnets to the experimental target. A number of beams also use a combination of electric and magnetic fields to select particles of a particular type, especially K mesons and antiprotons, which are produced less copiously than pions.

Figure 1. A full size prototype of the liquid scintillator calorimeter for AGS Experiment 734 is shown. The prototype was constructed of 40, 4″ × 4″ extruded acrylic tubes. This unit, weighing over a ton, is suspended by a "venetian blind" of stainless steel straps weighing less than 10 pounds.

NEUTRINO EXPERIMENTS

Experiment 704, (Harvard/BNL) has concluded a search for neutrino oscillations, in which the transformation $\nu_\mu \rightarrow \nu_e$ would be observed through the reaction $\nu_e n \rightarrow e^- p$. Approximately 10^{19} protons at 1.5 GeV/c were targeted and when the current analysis is finished they should be able to place a limit of close to 1 eV on the mass difference between the two different neutrinos.

The Fermilab experiment by a Columbia/BNL collaboration studying neutrino interactions in a bubble chamber filled with a neon-hydrogen mixture found 249 opposite sign dilepton events, an amount equal to the sum of the events from all other similar experiments. The excitation curve has now been measured and for the first time there is clean evidence for Λ's in dilepton events, implying the presence of charmed baryons. Hadronic decays of the charmed baryons Σ^{++} and Λ^+ were observed primarily through the decay $\Sigma^{++} \rightarrow \Lambda^+ \pi^+$ followed by $\Lambda^+ \rightarrow \Lambda\pi^+$ or $\Lambda^+ \rightarrow K^o p$.

The major new neutrino experiment at BNL will be Experiment 734 (BNL/Brown/Pennsylvania/KEK) which will study elastic neutrino scattering from electrons and protons. Detail design and testing of prototype proportional drift tubes and liquid scintillator modules were completed. The major construction of the detector has begun and the installation of the first modules in the block house is underway. A prototype of the liquid scintillator calorimeter is shown in Fig. 1.

HADRON SPECTROSCOPY AND REACTIONS

Several experiments were performed in the Multiparticle Spectrometer (MPS), which is operated by BNL as a facility for all users. The MPS, which is shown in Fig. 2, is based on a large dipole magnet operating at 10 kG. Many planes of counters within the magnet are used to record the tracks of all the charged particles produced in an event. A Cerenkov counter downstream of the magnet provides particle identification. In a typical experiment, information from several of the counters is combined electronically to determine if the event is potentially interesting. If so, the information from all of the counters is recorded on magnetic tape and subsequently processed by a computer to reconstruct and analyze the event.

Using the MPS, Experiment 557 (BNL/Brandeis/CCNY/Massachusetts/Pennsylvania) studied K* resonances in the reaction $K^- p \rightarrow K^0 \pi^+ \pi^- n$ at 6.0 GeV/c. Since it is a charge exchange reaction, the usual large Deck type background is greatly suppressed and the results are quite clean. A detailed particle wave analysis was performed on the 2^+ K* (1430) resonance, and very strong evidence was found for the 1^+ Q_2 (1400) resonance. Along with these known resonances, substantial evidence was found for a new 1^- resonance at 1450 MeV. Although the statistics were limited at higher mass, the 3^- K* ($\sim$ 1800 MeV) resonance was clearly detected.

During the current year, a BNL/CCNY/Vanderbilt/Tufts (Experiment 705) group will carry out an experiment at the MPS to study the reactions $\pi^- p \rightarrow K^o_s K^o_s n$ and $\pi^- p \rightarrow \Lambda\bar{\Lambda} n$ at 23 GeV/c. The $K^o_s K^o_s$ final state is restricted to the quantum numbers $J^P = 0^+, 2^+, 4^+ \ldots$. This restriction reduces the non-resonant background and makes possible the observation of new resonances produced with small cross sections.

Current MPS experiments are concentrated on searching for charm particle production in hadronic reactions and on studying baryonium, high mass mesons which decay primarily into baryon-antibaryon pairs. These include Experiment 682 (BNL/CCNY/Massachusetts/SMU), Experiment 686 (BNL/Stony Brook/Pennsylvania/Syracuse/Brandeis/Cincinnati), Experiment 688 (Syracuse/Brandeis/Cincinnati/BNL), and Experiment 716 (CMU/SMU/BNL).

In Experiment 641 (BNL/Case) data are being analyzed to measure the polarization in $K^+ n \rightarrow K^+ n$ at the momentum of 800 MeV/c. This requires observing a left-right asymmetry in a second scattering of the recoil neutron. A broad increase has been observed in the $K^+ n$ cross section at this momentum, and the polarization will determine whether this bump is a true resonance. If so, its quark structure must be uudds, and it will be the first established five-quark baryon.

Experiment 732, a BNL/Princeton/Illinois collaboration has been set up and has taken a short data run in search of the η_c, the pseudoscalar state of charm-anticharm quarks. Previous candidates observed at DESY and Serpukhov at

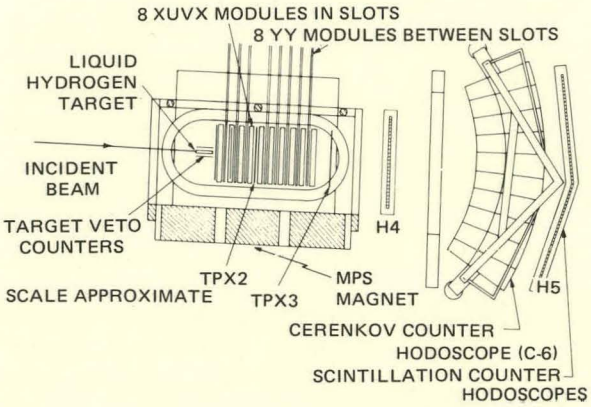

Figure 2. The Multiparticle Spectrometer. Particles produced in the liquid hydrogen target are tracked by counter modules inside the magnet, which is 6 m long. The curvature of each track determines its momentum. The Cerenkov hodoscope downstream of the magnet can distinguish different types of particles.

2.85 GeV appear at too low a mass to be compatible with theoretical expectations. The search is being conducted at the AGS in the reaction $\pi^- p \rightarrow \eta_c n$ at 13 GeV/c, with subsequent η_c decay into two γ's. A two-arm γ detector is employed consisting of a combination of scintillation counters, lead converters, and lead glass Cerenkov counters to measure the positions and energies of the γ's. The system has been demonstrated to be extremely effective in detecting γ's and in discriminating against π^0 mesons, which can simulate γ's and be a source of background. In the short data run taken, no digamma events were observed above 2.2 GeV. The main data-taking run is scheduled for this year and will have two orders of magnitude higher sensitivity than the short run in early 1979. For the estimated product of the branching ratio and the production cross section $BR(\eta_c \rightarrow \gamma\gamma) \cdot \sigma\,(\pi^- p \rightarrow \eta_c n) \sim 10^{-35}$ cm^2, 25 events are expected with negligible background.

A LBL/Mt. Holyoke/BNL collaboration did a series of experiments (Experiments 733, 730, 738) on the nature of the low energy $\bar{p}p$ interaction. The cross section for $\bar{p}p$ backward elastic scattering was measured between 406 and 922 MeV/c with a recoil spectrometer. Although the resolution was ± 2 MeV in the region of the S(1932) meson, the narrow resonance was not observed. Furthermore, no enhancement was observed at a mass of 2020 MeV, where a structure had been reported in a production experiment.

The same group also measured the charge exchange cross section, $\bar{p}p \rightarrow \bar{n}n$ over the momentum range 119 to 1046 MeV/c with a resolution of 15 MeV/c FWHM; again no enhancements were observed in the vicinity of 1932 or 2020 MeV. The total and annihilation cross sections for $\bar{p}p$ and $\bar{p}d$ were then measured from 355 to 1066 MeV/c; again no pronounced narrow structures were observed. The data did suggest a 20 MeV-wide structure with a small cross section in the $\bar{p}p$ total and annihilation cross sections at a mass of 1940 MeV. However, the significance of this enhancement is very sensitive to the background parameterization. No structure was observed in $\bar{p}d$. Taken together, these results make it difficult to explain the narrow structures reported by other groups.

A proposal by a BNL/Case Western Reserve collaboration (Experiment 742) to measure the total cross section, the annihilation cross section, and the elastic cross section in $\bar{p}p$ interactions in the region of the S meson has been approved. This experiment should resolve the controversy generated by the conflict between the results of two older experiments, both of which saw the S meson, and the more recent experiment which did not observe the S meson. The proposed experiment is a significant improvement with respect to systematic efforts since it uses a low mass drift chamber system. This experiment should be running and collecting data this year.

The $\bar{p}d$ annihilation cross section was measured by a Syracuse/Michigan State/BNL collaboration (Experiment 708) and these data are in the final stages of analysis. The experiment is now scheduled to search for discrete γ rays arising from transitions between pp bound states using a pair spectrometer.

HADRON DYNAMICS

An experiment at the CERN Intersecting Storage Rings by BNL/CERN/Syracuse/Yale observed the first unambiguous signal for direct single photon production in hadronic interactions. The ratio of direct photon to π^0 as a function of transverse momentum is shown in Fig. 3. The separation of such photons from the background of $\pi^0 \rightarrow \gamma\gamma$ was made possible by the

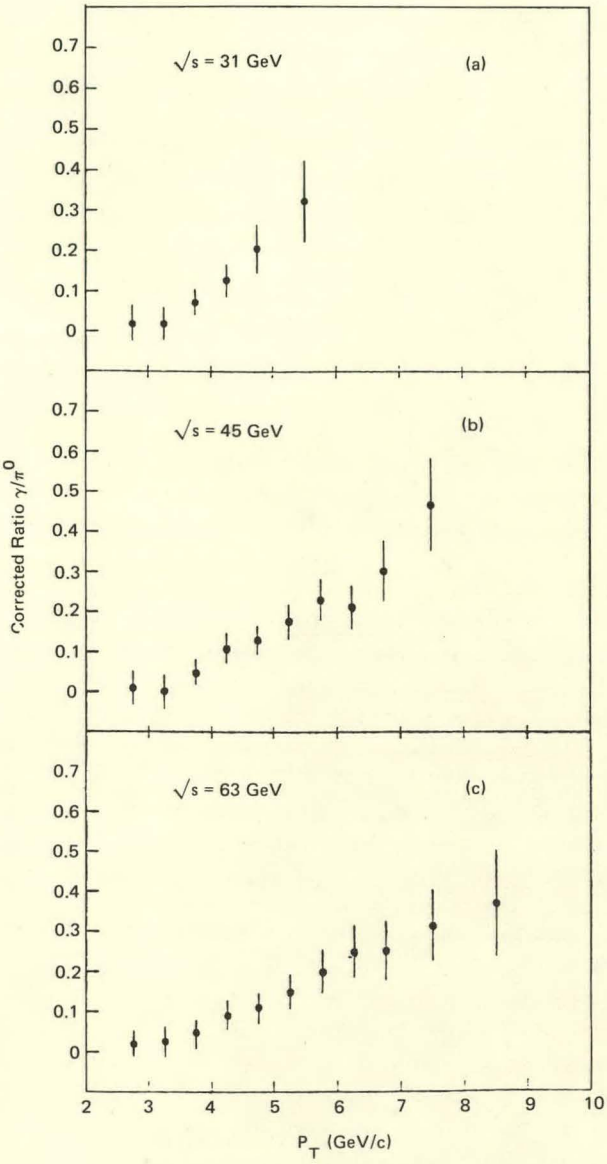

Figure 3. A plot of the ratio of directly produced γ rays to directly produced π^0's is shown as a function of transverse momentum. The three different plots correspond to the three different energies of the proton-proton colliding system that were run at the ISR.

excellent spatial resolution of the lead/liquid argon calorimeter. The multiplicity of associated charged particles has been found to be lower for single photons than for π^0, in agreement with expectations from quantum chromodynamics. The studies of single photons will continue using these calorimeters with the Axial Field Spectrometer. In addition, from the present data, cross sections for the J/ψ and the Υ resonances and for the e^+e^- continuum are being determined. Production of single π^0's, η's, and ω's at high transverse momentum are being studied together with correlations between two π^0's and between a π^0 and an η. All of these results have direct bearing on the application of quantum chromodynamics to hadronic interactions.

A large polarization was observed by University of Massachusetts/BNL for inclusively produced Λ^0's from nuclear targets at Fermilab and at the AGS. Therefore, a measurement of the polarization of Λ^0's with hydrogen and deuterium targets, Experiment 717, was undertaken by that group to determine whether the polarization of Λ^0's produced from free neutrons and protons is smaller, as was indicated by another Fermilab experiment. In contrast to the Fermilab results, the polarizations observed from hydrogen and deuterium at AGS energies are larger than those measured in production from nuclear targets. These results are shown in Fig. 4. The same collaboration plans to measure Σ^0 polarization.

A NYU/BNL collaboration, Experiment 726, will search for the production of charmed particles in hadronic interactions via the $K^+\pi^-$ decay of the D^0 near threshold. Charm should be observed if the cross section exceeds 20 nb. Observations of hadronic charm production would be interesting from the viewpoint of reaction dynamics and would provide a tool for studying charmed baryon spectroscopy.

Weak Decays of Hadrons

In Experiment 696, a BNL/Yale collaboration is completing an analysis of the measurement of the polarization of muons in the decay $K^0 \rightarrow \mu^+ \pi^- \nu$. Figure 5 shows the polarimeter used in this experiment. If time reversal (T) invariance is obeyed in that decay, the muon polarization will lie in the decay plane. In terms of the usual parameter ξ which describes that decay, T invariance predicts Im $(\xi) = 0$, after correcting for the small electromagnetic efforts in the final state. This measurement gave Im $(\xi) = 0.012 \pm 0.026$. In order to have sufficient precision to decide between the milli-weak and super-weak theories this group is now conducting a new experiment, Experiment 735, to measure Im (ξ), in the decay

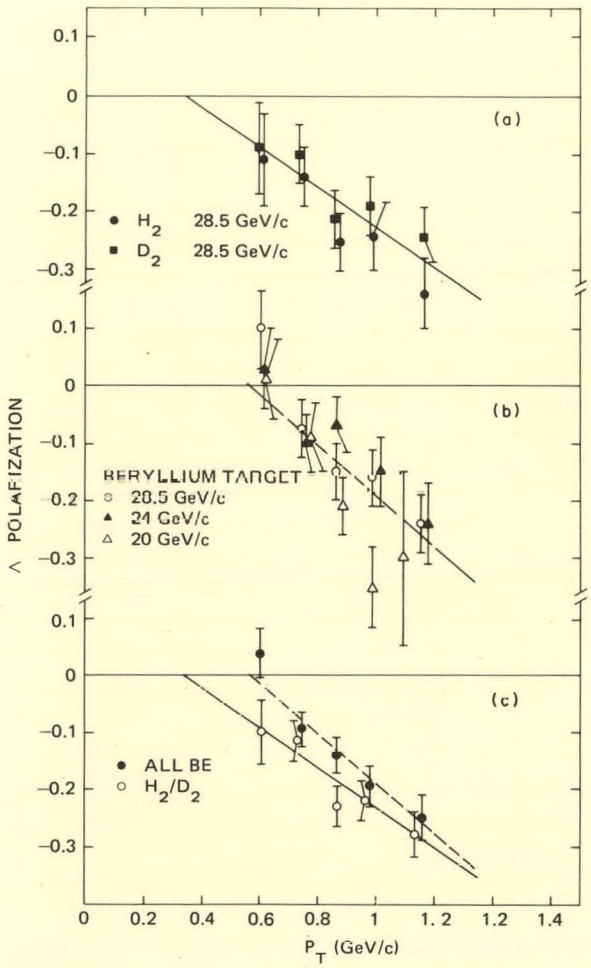

Figure 4. A plot of the polarization of Λ's as a function of transverse momentum as obtained by AGS Experiment 717. The various plots show results on different targets and slightly different incident proton momentum.

$K^+ \rightarrow \mu^+ \pi^0 \nu$, with an order of magnitude improvement in precision.

A Yale/BNL/Mt. Holyoke collaboration, Experiment 702, will begin a measurement of the asymmetry in the decay of polarized Σ^+'s in the decay $\Sigma^+ \rightarrow p\,\gamma$. Longitudinally polarized Σ^+'s will be produced through the reaction $K^- p \rightarrow \pi^- \Sigma^+$ using a polarized proton target and several thousand radiative weak decays will be obtained.

HIGH ENERGY THEORY

The High Energy Theory group has made progress over a wide spectrum of problems with most effort being concentrated on understanding the decays of the new particles, on studies of classical non-Abelian gauge theories, on application of Monte Carlo methods to the study of quark confinement in gauge theories, and on the application of quantum chromodynamics (QCD) to the production of $W^{\pm}$'s, Z^0's, lepton pairs, and hadron jets in high energy collisions.

Monte Carlo techniques were developed and applied to quantized gauge theories defined on a space-time lattice. Such theories can be regarded as statistical mechanical systems, with the coupling constant playing the role of temperature. Their properties can be studied by a computer simulation in which the lattice system is brought to "thermal" equilibrium. Results have been obtained for gauge theories based on the groups Z_N, U(1), SU(2), and finite non-Abelian subgroups of SU(2) in four space-time dimensions and for various spin systems in two dimensions. In particular, interesting phase transitions are found in theories based on Z_N and finite non-Abelian groups. A phase transition is also found for U(1) but not for SU(2). This implies that the SU(2) theory—and presumably the SU(3) one—have only the strong-coupling phase, which produces confinement, while the U(1) theory has another phase that corresponds to electromagnetism. Efforts are being made to extend the calculations to SU(3) and to include quarks.

Work has continued on the comparison of experimental data with the predictions of the standard (Weinberg-Salam) model of weak and electromagnetic interactions as well as a left-right symmetric model. It has been concluded that the differences between the predictions of these two models could become significant only at energies exceeding those of present machines.

The decays of bound systems of heavy quarks have been extensively studied. The very important Okubo-Sweig-Iizuka rule has been examined in the framework of QCD. It was found that the lowest order prediction of narrow widths is not destroyed by the effects of emission of soft gluons. As a result, the bound state energies and widths can be calculated as a series in $\alpha_s \ln\alpha_s$.

Bounds on the quark mixing angles in the six-quark model were established, and the SU(3) predictions for charmed-meson decay were worked out. Dynamical calculations, in specific

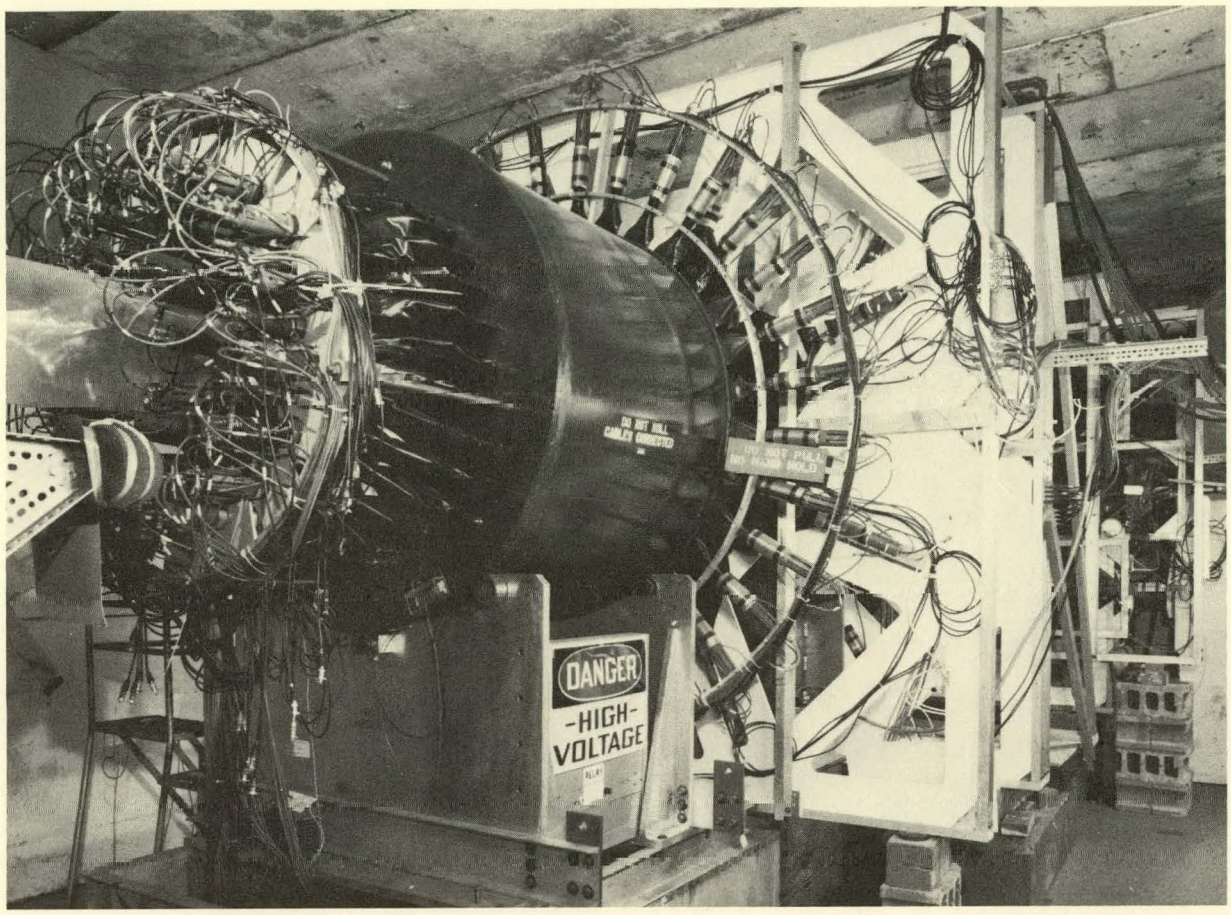

Figure 5. The polarimeter used in AGS Experiment 696 to test time reversal invariance in K^0 decays.

models, of decays of the charged D mesons were performed and are in rather good agreement with data for the lifetimes and the branching ratios.

Higher order QCD corrections to the Drell-Yan model of lepton pair production were calculated and found to be large, which cast doubt on the quantitative reliability of that model. Updated estimates of W production were made, particularly regarding the use of polarized protons and the modifications due to scaling violations. The scaling violations lead to more rapid energy variations than was found in the naive quark-parton model, with cross-sections nearly the same in both models for ISABELLE energies.

Members of the BNL Physics Department engaged in High Energy Research are included in the staff list starting on page 50.

Accelerator Department

INTRODUCTION

The Accelerator Department is responsible for the operation of the major high energy facilities at Brookhaven, principally the Alternating Gradient Synchrotron (AGS).

At the AGS, protons are accelerated to high energies and then produce beams of secondary particles. These particles are transported by systems of magnets to areas where they are used to perform particle physics experiments. The Department oversees the scheduling of these experiments and provides services to user groups such as on-line computing, rigging help, and the use of large experimental facilities such as the Multiparticle Spectrometer (MPS).

Other work within the Department includes heavy ion-initiated fusion, neutral beam development, and superconducting power transmission.

* * * * * * *

The AGS

To begin the acceleration process, protons are produced by passing an electrical discharge through hydrogen gas. The protons are collected and made to enter a Cockcroft-Walton preinjector where they are accelerated to 750 keV. They are then accelerated in a 200-MeV linear accelerator (linac) and injected into the AGS.

The AGS is a proton synchrotron of the alternating-gradient type. The basic element of a synchrotron is the ring of magnets which guides the protons around an approximately circular path, and which also applies a restoring force to particles which leave the central orbit. In the AGS the shape of the magnetic field is reversed (alternating gradient) many times around the ring. This provides the strong focusing necessary to keep the beam confined to a small central region, which is important since the beam circulates entirely within an evacuated beam pipe lodged in the magnet gaps. While traveling in their almost circular trajectories, the protons are accelerated in rf cavities, located at several points around the ring, up to an energy of 29 GeV. They are then ejected from the main ring and sent down beam lines to target stations where they can be used by the experimenters. This process is repeated cyclically, with a repetition period of 1.5—2.5 sec.

Since the extracted proton beam is often split among several experiments simultaneously, it is desirable to achieve the highest possible intensity. In this regard, the AGS has been continuously improving during the last several years. The standard intensity is now more than 0.9×10^{13} protons/pulse while an intensity averaging over 10^{13} for an eight-hour shift has been achieved. The record peak intensity is 1.117×10^{13} protons/pulse. Figures 1 and 2 give the accumulated total protons accelerated and the total hours available for doing high energy physics experiments for the past several years. As can be seen in Fig. 1, 4.5×10^{19} protons were accelerated in FY 1979 (the period covered by this report), a 35% decrease over the record year of FY 1978. The operating efficiency, defined as the ratio of total high energy physics hours over the sum of physics beam hours and unscheduled downtime, was 71% in FY 1979. For 37 weeks of operation the average number of high energy physics hours available per week was 94. The average intensity per pulse in FY 1979 was 0.68×10^{13} protons/pulse; this includes the periods when the machine was purposely detuned to meet certain experimental demands.

There are two extraction modes at the AGS. In the slowly-extracted-beam mode (SEB) the circulating beam is first debunched and then slowly

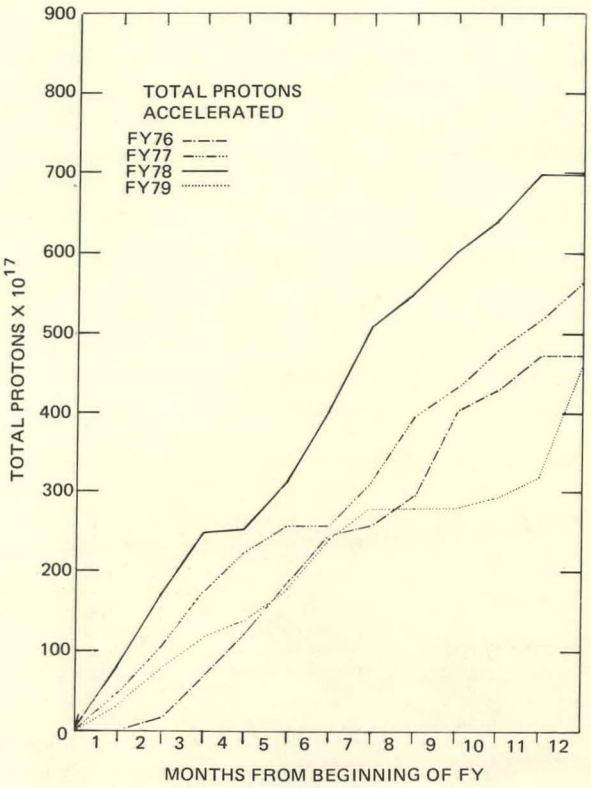

Figure 1. AGS performance: total number of accelerated protons.

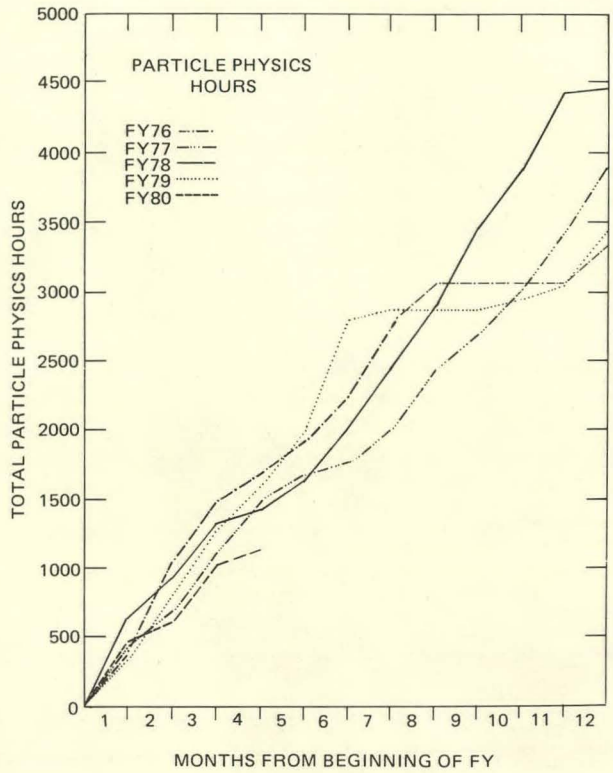

Figure 2. AGS performance: total hours of high energy physics research.

extracted over many turns. This is accomplished by gradually "shaving" off some of the beam particles with an electrostatic septum, and then directing them to external beam lines by means of bending magnets. The whole beam is extracted in this way in the course of about one second. This relatively long time allows experimenters to take data smoothly without overloading their detectors. For neutrino experiments, where the interaction rates are much smaller, it is desirable to receive the full beam over a short period. In the fast-extracted-beam mode (FEB), the proton beam is not debunched, and is fully extracted in only one turn. In this case, the beam pulse is delivered within a few microseconds.

In addition, the 200 MeV linac (which injects into the AGS) was extensively used by the Brookhaven Linear Isotope Producer (BLIP), the Chemistry Linac Irradiation Facility (CLIF), and the Medical Proton Radiogram Facility. The total 200 MeV proton flux delivered to BLIP in FY 1979 was 0.11 ampere hours.

IMPROVEMENTS TO THE AGS

Slow Extraction Efficiency

The principal focus of improvements to the AGS over the past two years has been on the SEB. As part of this effort, the slow extraction efficiency has been improved by bringing into operation an electrostatic septum (Fig. 3) in the main ring. Without the septum, the extraction efficiency has been typically 80 to 90%. With the septum now in routine operation, the extraction efficiency is 95 to 97%. In terms of useful protons delivered to targets, this is equivalent to an increase in nominal AGS intensity from 0.9 x 10^{13} to 1.0 x 10^{13}. Perhaps more important, the proton losses, and hence residual radioactivation and personnel exposure, have been reduced by a factor four.

SEB Switchyard

The proton beam transport between the main ring and the targets is referred to as the "switch-

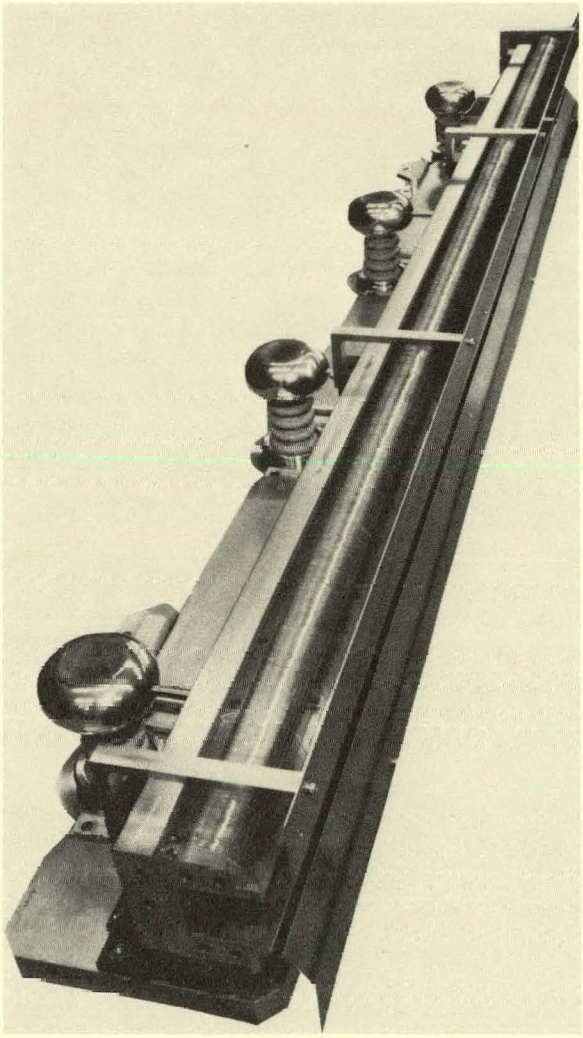

Figure 3. Electrostatic septum for AGS slow extraction which has improved the extraction efficiency from 80-90% to 95-97%.

yard" because of its resemblance to a railroad switchyard. In the past, the beam splitting function has been carried out by means of special copper septum magnets with typical septum thicknesses of 1 mm. Typical overall efficiency of this system was 70%. In FY 1979, a complete reconstruction of the upstream elements of the switchyard was carried out, culminating a three-year effort in planning, component development, component production, construction, and testing.

In the new switchyard, electrostatic septum beam splitters with septum thickness of 0.05 mm have been provided, and thicker, downstream septa are now of the Lambertson, or steel septum, type (Fig. 4). Crowded into the same space occupied by the old system are components to provide a four-way rather than three-way split, thereby feeding the existing A, B, and C line target stations along with a new D target station, presently under construction. The design efficiency is 95%, a factor six less loss than with the old system.

Some statistics on the switchyard project are as follows: people involved — 250; new types of electrostatic septa and magnets designed and developed — 5; new magnets constructed — 26;

Figure 4. A Lambertson magnet in the new switchyard. At this point, the beam has already been split by upstream thin septum electrostatic and Lambertson magnets into four parts: the D and A beams, which are bent in the main magnetic field, and the B and C beams, which pass undeflected through the hole bored in the magnet pole tip.

total magnets installed — 40; additional magnets repowered — 51; vacuum piping installed — 157 m; high current dc cable installed — 6.1 km.

Switchyard commissioning went smoothly. Beam was transported in the first few hours of the initial test with all magnets at calculated values. Figure 5 shows a fluorescent flag image of the split beams near the entrance of the magnet of Fig. 4. The images of the A, B, and C beams are shown along with the calculated position of the future D beam. At the time of writing, the system is in operation, but with the AGS at only half its nominal intensity because of experimental requirements. It is anticipated that the full system capabilities will be required shortly, as the SEB experimental program comes into full operation after its one-year shutdown.

Qualitative indications are that beam sizes and switchyard performance agree with design predictions. For example, residual radioactivity levels eight hours after shutdown near the electrostatic septa and Lambertson magnets are 100 mR/h, compared to 2000 mR/h for the copper septa in the old switchyard. Quantitative measurements will be carried out when high intensity operation begins.

H^- Injection

By injecting negative hydrogen ions into the AGS and stripping the electrons in a thin foil inside the main ring, a source of protons is created which allows multiturn injection into the same phase space. The use of this method of injection should provide a brighter beam with better control over emittance matching for ISABELLE injection. It is also anticipated that this improvement project will greatly reduce residual radiation problems in the injection area of the AGS. A source of H^- ions has been built and tests of its operating characteristics are underway. The second Cockroft-Walton terminal at the Linac is being prepared for this source and the injection area of the AGS will be altered to meet the new requirements.

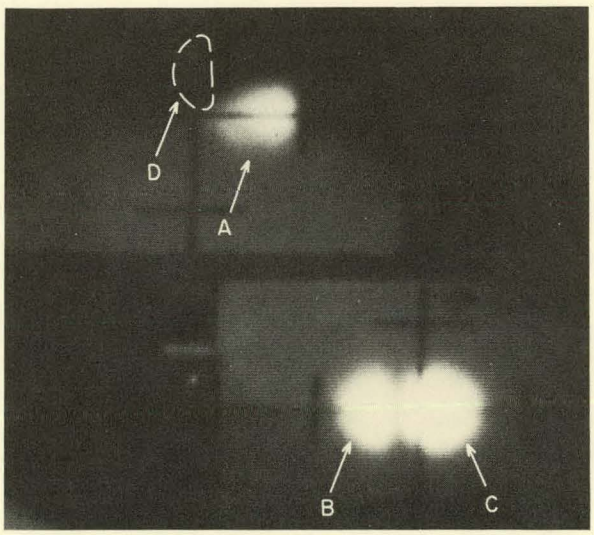

Figure 5. Fluorescent flag image of the split beams at the entrance of the magnet of Fig. 4. The images of the A, B, and C beams are shown along with the calculated position of a future D beam.

Other Improvements

In addition to the SEB and H^- work, improvements have been made in a number of other AGS systems and other improvements are under way or planned.

A system of stabilizing the AGS energy at fast ejection or flattop has been brought into operation. A microprocessor controlled system of loss monitors around the AGS ring was built and is now in routine operation. It has proven useful for machine diagnostics of many sorts. A new longitudinal pickup electrode has been built for measurements of the bunch shape, with good high frequency response and low distortion. Difficulties with the transverse pickup electrode system, which was built as part of the AGS Conversion, have been diagnosed and the system is being brought into operation for accurate measurements of proton orbits in the AGS. All of these devices will be useful tools in studies and development for use of the AGS as an ISABELLE injector.

Rewinding of the stator of the old Westinghouse motor generator set is underway in order to make it compatible with the existing Siemens' rectifier and switch gear. The Westinghouse motor generator will then be a backup spare for the rotating machinery in the Siemens set. A project to replace the corroded main vacuum chamber is underway. Performance of the AGS control system has been enhanced by installing an additional PDP-10 backup computer (System D).

Future Plans

Two main projects will occupy the AGS Division in the next few years. These are preparation of the AGS to be an injector for ISABELLE, and

the acceleration of polarized protons. These projects are currently in the design stage.

EXPERIMENTAL PLANNING AND SUPPORT

The beam extracted from the AGS is sent either to the North Area, for neutrino experiments in the fast-extraction mode, or to the East Area in the slow extraction mode. Table I summarizes the activity in these areas during the year.

Since January 1978, 34 experiments and approximately 50 test beam groups received beam time at the AGS. Thirty-seven experiments were installed and 30 completed taking data. Many of these required modifications to existing facilities. Notable was a period of running at 1.5 GeV/*c*. A Harvard/BNL experiment designed to search for $\nu_\mu - \nu_e$ regeneration required a high intensity pion beam with a minimal kaon component. This suggested running the AGS at a reduced energy, but in order to bring low momentum protons to the FEB production target, a substantial number of quadrupole magnets were added to the beam transport system. This mode of operation is now routinely available.

Because of the increasing interest in low energy antiproton and kaon physics, a second low energy separated beam, LESB II, was recently constructed at the AGS. During the past year, the first round of experiments was completed. These included two complementary studies of low lying "baryonium" states.

As experiments have become more complex, so has their installation on the AGS floor. It is now routine for an experiment to require the almost complete reconstruction of a secondary beam. For example, the C1 high intensity pion beam (10^9/pulse at 14 GeV/*c*) is undergoing extensive modifications to accommodate a momentum tagging hodoscope for an NYU/BNL study of hadronic charm production. Another reconstruction under way is at A3. Here, a K^0 beam is being converted to K^+s. This will permit a Yale/BNL group to refine its measurement of the T-violation parameters as measured in $K^+\mu_3$ decay, where final state electromagnetic interactions are absent.

Table I
Experimental Program at the AGS during FY 1979

Beam	Exp. No.	Institution Description of Experiment	
A1	682	Brandeis/BNL/CCNY/U. Mass/Southeastern Mass. Search for charmed particles and baryonium, e.g., $\pi^- p \rightarrow D^- D^0 p$ (16 GeV/c) $\rightarrow K^+\pi^-\pi^-$	Complete
A3	696	Yale/BNL Measure the CP violating transverse muon polarization in $K^0_L \rightarrow \mu^+\pi^-\nu$. Test for "milliweak" force as source of CP violation.	Complete
B1	732	BNL/Princeton/Illinois Search for the η_c. The reaction $\pi^- p \rightarrow \eta_c n$ $\rightarrow \gamma\gamma$ is studied. The γ's are detected in a lead glass array and the neutron time-of-flight is measured.	To be completed
B2	698	U.Mass Polarized target physics with the MPS. A "spin refrigeration" polarized target has been built which requires neither microwave nor a highly uniform magnetic field. It will be installed in the MPS. $K^- p\uparrow \rightarrow Y^+ \pi \rightarrow \Lambda\pi^+\pi^-$ reactions will be studied near 2 GeV/c.	To be completed

Table I (Cont'd)
Experimental Program at the AGS during FY 1979

Beam	Exp. No.	Institution Description of Experiment	
B2	673	Brandeis/Florida State/Syracuse/BNL Ξ^* resonance study. $K^-p \rightarrow \Xi^{-*}K^+$ $\rightarrow \Lambda K^-\pi^0, \Lambda K^-\pi^+\pi^-$.	Complete
B4	722	BNL Search for exotic 6-quark states. A double-arm spectrometer triggers on two K^+'s in reaction $p + p \rightarrow K^+ + K^+ + X$. Exotic states observed as missing mass peak.	Construction
B5	717	BNL/U. Mass/Michigan Λ polarization from proton interactions in hydrogen and deuterium targets, map s, P_T dependence.	To be completed
C2	728	BNL/Princeton/MIT/Houston/Vassar/Carnegie-Mellon Search for Σ hypernucleus using a deuterium target. $K^- + d \rightarrow (\Sigma^-N) + \pi^+$; $K^- + d \rightarrow (\Sigma^+n) + \pi^-$.	Complete
C2	646	BNL/Princeton/MIT/Houston/Vassar/Carnegie-Mellon States of ^{12}C formed in the reaction $^{12}C(K^-,\pi^-)^*$	Complete
C2	692	Carnegie-Mellon/Houston $K^\pm$ elastic scattering from selected nuclei at ~ 800 MeV/c. Hypernuclear spectrometer of E646.	Complete
C4	733	LBL/Mt. Holyoke/BNL $\bar{p}p$ backward elastic scattering.	Complete
C4	730	LBL/Mt. Holyoke/BNL Measurement of the $\bar{p}p$ charge exchange cross section.	Complete
C4	738	LBL/Mt. Holyoke/BNL Study of $\bar{p}p$ total cross section.	Complete
C6	701	U. Calif., Irvine/LASL/New Mexico/Temple Search for bound states and resonances in nucleon-antinucleon interactions. $\bar{p}p$ and $\bar{p}n$ interactions $0 \leq Pp < 500$ MeV/c. Detect the recoil neutron and time of flight => mass on NN system. NaI detector to identify radiative de-excitations ($\geq$ 15% energy resolution). Mass resolution 0.7 (T_n => 5 MeV) – 27 MeV (T_n = 85 MeV).	To be completed
C8	708	Syracuse/Brown/Michigan State/BNL Search for γ transitions in $\bar{p}p$ annihilations at rest and low energies. Search for the Cosmion. Magnetic pair spectrometer with 1 MeV γ energy resolution.	In progress
U	704	Harvard/BNL Search for oscillations of a long-lived neutrino beam. The time evolution of a long-lived ν_μ beam is studied searching for a ν_e signal in a large detector. Primary 1.5 GeV/c protons are used to produce a high-flux, low background beam.	Completed
U	734	BNL/Brown/Pennsylvania/KEK Measurement of elastic scattering of neutrinos from electrons and protons. These are weak neutral current processes. The outgoing electrons or protons in the reactions $\nu_\mu e \rightarrow \nu_\mu e$ $\quad$ $\nu_\mu p \rightarrow \nu_\mu p$ will be identified by their characteristic behavior in a large aluminum-scintillator-proportional wire counter detector.	Construction

Table I (Cont'd)
Experimental Program at the AGS during FY 1979

Beam	Exp. No.	Institution Description of Experiment	
U	737	BNL/Tohoku Study of neutrino interactions in deuterium in the 7′ bubble chamber.	Completed
U	739	U. Calif., Irvine/U. Calif., San Diego/Arizona/LSU/Wisconsin/Hawaii Studies of acoustic pulses emitted in proton-nucleus interactions.	Completed

Neutrino experiments have also become more complex, as rarer processes are being studied. Experiment 734, a Penn/BNL/Brown study of $\nu_\mu e$ and $\nu_\mu p$ elastic scattering, is under construction in the North Area. A new blockhouse of 8100 tons (m) (36.6 × 15.2 × 7.6 m) has been built to accommodate a detector consisting of interspersed proportional counters and 113,500 liters of liquid scintillator.

A facility made possible by the new switchyard is a fourth, D, target station. It will be located so as to make use of an area on the AGS floor freed by the removal of the internal, G10, target and associated secondary beams. While the experimental program at the D station has not been definitely settled, it is likely that it will include a Michigan/Argonne/BNL study of p-p scattering from a polarized target and the operation of a low energy muon channel, obtained from the NASA Space Radiation Effects Laboratory (SREL).

In order to transport primary protons to the D station, a 21° bend is required. Two 6-T superconducting magnets will be used to produce this bend. The magnets are now under construction. They are based on ideas developed for the 4-T magnets (8°), which have been in operation for seven years in the FEB transport system. They will incorporate a curved bore to compensate for the sagitta of the 28 GeV/*c* protons.

As the USA bubble chamber programs have been phased out, an increasing number of experimental groups have made use of the MPS. This facility provides a large number of electronic detectors embedded in a large magnetic volume. In order to make possible the study of rarer processes, the facility is being upgraded to accommodate higher beam intensities. Spark chambers will be replaced by high-resolution drift chambers while the on-line computing capacity has been increased. The new chambers will make use of an amplifier, a discriminator, and an integrated circuit shift register, developed especially for this purpose.

Work has advanced on new types of equipment which can operate in the high data-rate environment of ISABELLE. The presently available types of modular electronics (NIM and CAMAC) are not adequate. A FASTBUS system has been developed which can more closely match the requirements of economy and speed. In a sense, the system extends the computer to include what had until now been the "experimental" electronics. Several FASTBUS elements have been built and they will be used in the Yale/BNL T-violation experiment in the spring of 1980. Another effort directed to ISABELLE is the construction and instrumentation of an area for use by the ISA Detector Division. Prototypes of calorimeters and scintillation fiber hodoscopes are currently being evaluated there.

A major BNL commitment of the past year was the decommissioning of the NASA Space Radiation Effects Laboratory (SREL) in Virginia and the relocation of a large amount of salvaged equipment to Brookhaven. In addition to the low energy muon channel, 13,600 tons (m) of concrete shielding and the 2500 ton SREL cyclotron magnet were moved to BNL. Much of the shielding is already in use, particularly in the new blockhouse in the neutrino area. The final disposition of the cyclotron at BNL is still uncertain; one possibility would be as the basis for an ISABELLE experimental detector facility.

NEUTRAL BEAM DEVELOPMENT

The objective of the BNL Neutral Beam Program is to develop a 250 keV neutral beam system suitable for heating experiments in toroidal or mirror plasma devices. The system will be based on acceleration and neutralization of negative hydrogen ions produced in and directly extracted from a source. The objective of source studies is to develop a unit delivering 10 A of negative ions in pulses of 1 sec duration or longer, operating with extracted current densities of at least 0.5 A/cm^2 and having acceptable power and gas efficiencies, and good beam optics. The 250 keV accelerator development work covers different structures, including those separated from the source by a bending magnet or a beam transfer system. During FY 1979 substantial progress was achieved toward the objectives of the program; in the same period the BNL program was reviewed by a panel, resulting in suggestions for a better orientation toward prospective users' requirements and in establishment of contacts with Princeton Plasma Physics Laboratory (TFTR Project) and Lawrence Berkeley and Livermore Laboratories (MFTF Project). A cooperative effort with Westinghouse was initiated in the second half of FY 1979 in order to utilize industrial facilities and expertise.

Two types of direct extraction ion sources have been studied, a standard magnetron source and a Penning source with an auxiliary electrode to enhance the H^- production. In either source a hydrogen-cesium plasma is established in the interelectrode gap and serves as the source of particles to bombard a cesium-covered electrode (cathode, auxiliary electrode), where negative hydrogen ions are produced. All BNL sources are of a compact design and operate with high extracted H^- current densities (space charge limited); for operation with pulses longer than 0.1 sec source electrodes and extractor grids have to be cooled. In addition to the magnetron and Penning sources, a new planar magnetron has been under consideration because of a substantially improved power efficiency and possibly an improved gas efficiency. Although the size of existing sources does not allow H^- current yields above 1 - 2 A in pulses longer than 0.1 sec, once the preferred configuration has been identified a large, cooled module will be designed to deliver 10 A in a long pulse/steady state mode of operation.

HEAVY ION FUSION

During the year, a new concept for the acceleration of charged particles was developed; a 500 kV Cockcroft-Walton accelerator for xenon was put into operation and an electrostatically focused 2 MHz Wideröe linac was under rf test.

The Multiple Electrostatic Quadrupole Array Linear Accelerator (MEQALAC) practically removes the conventional limitations on current in linear accelerators and in low energy beam transport systems. For instance, a 20-ampere linear acclerator to accelerate deuterium from 20 keV to a few hundred keV is now being designed. A conventional linac operating over this range would be current limited at a few milliamperes. A proof of principle MEQALAC device with nine beams has been built and was operated successfully. It accelerated xenon from 15.5 keV to 72 keV at 4 MHz. The accelerator reached 95% of the theoretical current limit, verifying the space charge theory and the practical feasibility of the concept.

The MEQALAC uses a unique property of electrostatic quadrupoles, which is that their strength increases as their size decreases. This allows one to transport space-charge-limited beams in very small channels, using higher frequencies than would ordinarily be the case and resulting in a smaller, less costly accelerator. Since many parallel beams can be accelerated together, the total current can be large. Figure 6 shows an electrostatic quadrupole array.

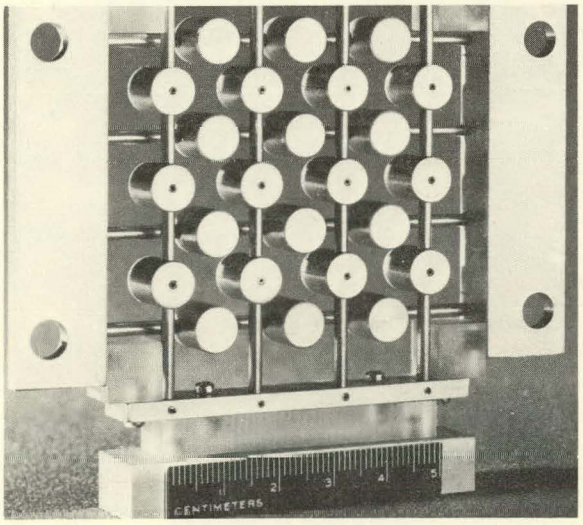

Figure 6. Electrostatic quadrupole array for use in MEQALAC.

The MEQALAC approach can also be applied to electron beams, where it is used to generate radiofrequency power. Called a MEQATRON, this concept makes possible a very efficient, compact 100-1000 MHz source. Because of the small beam sizes possible with MEQALAC technology, it may be feasible to construct MEQATRONs for millimeter wavelengths.

A table-top-sized MEQALAC is being built to replace the massive 750 kV Cockcroft-Walton pre-accelerator for the 200 MeV linac at the AGS. Development of the technology for the construction of still smaller and less expensive quadrupole arrays is proceeding. An array with 1000 beams per 6.25 cm^2 is now being fabricated.

The MEQALAC concept also leads to new possibilities for isotope separation and for controlled fusion by accelerating microscopic charged droplets of D_2 or DT.

SUPERCONDUCTING CABLES FOR POWER TRANSMISSION

Brookhaven is doing research on an underground superconducting power transmission system. Considering the economic and technological scale of the power industry, the possible implications of this work are enormous.

Cable samples up to 20 m long were tested under both high current and high voltage in the supercritical helium region. The high current test included simulation of a fault current which drove the cable normal—no damage was incurred during these severe conditions. Components for the high power terminations were evaluated and the design for a horizontally-mounted 4000 A coaxial lead is satisfactory.

The development of high-modulus polymer tape for use as insulation of both ambient and low-temperature cables continued. Many trial cables were taped using the machine erected at BNL. These cables were subjected to bending tests in order to correlate actual performance with theoretical analyses.

At the Test Facility the complete cryogenic system was operated at low temperature. A computer-based temperature monitoring system was brought online to collect and reduce temperature information during the run.

The Division was active in the US-USSR Technical Exchange Program in Superconducting Power Transmission. Two groups of Russian visitors performed joint experiments at BNL and two groups of US scientists visited the USSR.

ACCLERATOR DEPARTMENT

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Beam Design, Experimental Area Liaison, ISA Superconducting Magnet Properties, Particle Physics Research

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Beam Design, Experimental Area Liaison, Particle Physics Research, Superconducting Magnet Development

I-H. Chiang
Detectors, Electronics, Experimental Area Liaison, Particle Physics Research

G. T. Danby
ISA Superconducting Magnet Properties, Superconducting Magnet Development

B. DeVito
Mechanical Engineering, Superconducting Magnet Development

A. Etkin
Experimental Area Liaison, Multiparticle Spectrometer Facility, Particle Physics Research, Scheduling Physicist

D. I. Lowenstein
Control Systems, ISA Detector Magnets, Particle Physics Research

Y. Makdisi
Experimental Area Liaison, ISA Superconducting Magnet Properties, Particle Physics Research

T. W. Morris
Multiparticle Spectrometer Facility, Particle Physics Research

A. G. Prodell
Cryogenics, ISA Superconducting Magnet Properties

A. C. Saulys
Multiparticle Spectrometer Facility, Particle Physics Research

E. H. Willen
Experimental Area Liaison, Multiparticle Spectrometer Facility, Particle Physics Research

S. P. Yamin
Beam Design, Detectors, Experimental Area Liaison, ISA Magnet Development, Particle Physics Research

ATA DIVISION

E. B. Forsyth — Division Head

A. Ernst
Cable Insulation Development and Technical Monitoring of DOE Contracts.

R. J. Gibbs
Cryogenic Engineering of the Test Facility.

W. E. Harrison
Control and Instrumentation Engineering. Also Administrative and Budget Control Responsibilities.

J. E. Jensen
Deputy Manager of Superconducting Power Transmission Development. Coordination of Cryogenic and Mechanical Engineering.

C. J. Klamut (DEE)
Fabrication of Superconducting Tape.

A. J. McNerney
High-Voltage Testing of Cable Insulation and Terminations.

K. F. Minati
Mechanical Engineering of Laboratory Equipment and Terminations.

G. H. Morgan
Deputy Manager of Superconducting Power Transmission Development. Coordination of Scientific Effort.

A. C. Muller (DEE)
Development of Polymeric Insulation for Both Superconducting and Room-Temperature Cables.

ATA DIVISION (Cont'd)

T. R. Muller
Construction and Operation of the Taping Machine.

M. Suenaga (Part-Time DEE)
Metallurgy of Superconductors.

R. A. Thomas
Low Temperature Physics and Instrumentation.

F. Schauer (Visiting Appointment)
Design of High Voltage Bushing and Analysis of Power Losses of Superconducting Cables.

AGS DIVISION

Y. Y. Lee — Division Head

J. Alessi
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D. Barton
Chief AGS Operations, H^- Injection, Physics Research

D. A. Davis
Deputy Division Head, Power Distribution

D. Edwards, Jr.
AGS and ISA Transfer, Vacuum System, Physics Research

G. Gammel
Heavy Ion Fusion Project, Low Beta Acceleration, Physics Research, MEQALAC Development

W. Gefers
Electrical Engineering, AGS Security System

J. W. Glenn
AGS Operations, Accelerator Physics

A. Hershcovitch
H^- Ion Source Development, Physics Research

Y. Y. Lee
Fast Extraction System, ISA Transfer Polarized Protons, Physics Research

A. W. Maschke
Heavy Ion Fusion Project, MEQALAC Development, Physics Research

R. McKenzie-Wilson
Mechanical Engineering, H^- Ion Source Project

R. Mobley
Heavy Ion Fusion Beam Optics, MEQALAC Development, Physics Research

K. Prelec
H^- Ion Source Development, Physics Research

Th. Sluyters
H^- Ion Source and Acceleration, Physics Research

H. Weisberg
Accelerator Physics, Slow Extraction and Switchyard System

W. T. Weng
Accelerator Physics Theory, ISA Beam Transfer, Physics Research

The ISABELLE Project

ISABELLE (Intersecting Storage Accelerator), the major high energy physics construction project underway in the United States, will consist of two intersecting storage rings of about 500 superconducting magnets each. In these rings, 28 GeV/*c* protons from the AGS will be accelerated to 400 GeV/*c*. Head-on collisions between the two beams will be studied in six intersection regions, enabling the investigation of fundamental processes at extremely high energies.

Initiated as a development project in 1975, ISABELLE had progressed to the state of full Congressional Authorization in 1979, and in the spring of this year the annular area of 80 hectares, 4 km in circumference, was cleared and a preliminary survey completed. A design and construction supervision contract was signed with the firm Amman & Whitney Safeguard Construction Management Corporation, and contracts for completing the initial two-thirds of the machine tunnel awarded to the A.D. Herman Company. To date 380,000 m^3 of dirt have been moved, 34,000 m^3 of concrete poured, and 300 tons (m) of steel arch erected. Figure 1 shows the present construction schedule and Fig. 2 gives a recent aerial view of the site.

Figure 3 shows the layout of ISABELLE on the Brookhaven site, and Table I, some important machine parameters. A circular tunnel, 4.75

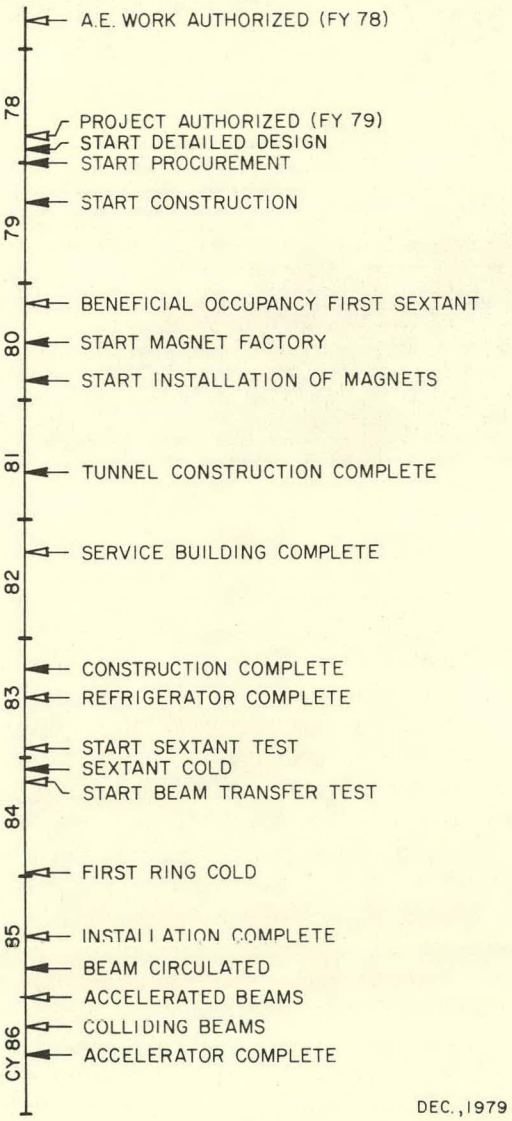

Figure 1. ISABELLE timeline.

Table I

Abridged Table of ISABELLE Parameters

Energy	
Maximum energy	400+400 GeV
Equivalent accelerator	320,000 GeV
Magnet System	
Circumference (4¾ × AGS)	3834 m
Bending field for 400 GeV	49.8 kG
Number of dipoles/ring	366
Number of quadrupoles/ring	176
Vacuum chamber diameter	8.8 cm
Injection	
AGS energy	29.4 GeV
ISA current/ring	8A
Number of protons/ring	6.4×10^{14}
Acceleration	
Duration	4 min
Energy gain/turn	25.6 keV
Peak rf voltage	48 kV
Experimental Regions	
Number	6

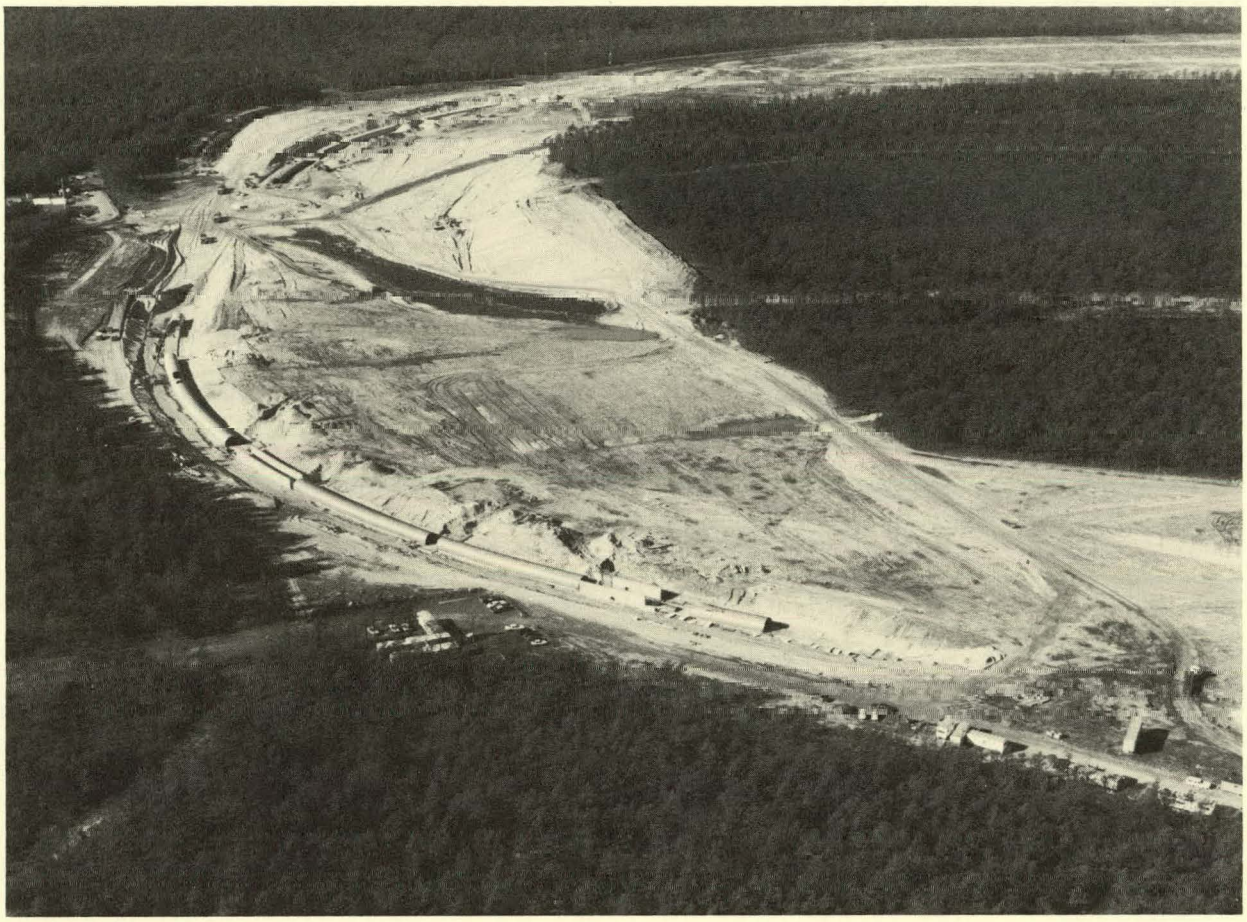

Figure 2. Aerial view of ISABELLE construction site.

times that of the AGS in circumference, will contain two adjacent rings of magnets (Fig. 4). Each ring will consist of superconducting dipole and quadrupole magnets for guiding the beams of protons. These two beams, circulating in opposite directions, will interact in six straight sections located symmetrically around the ring. Successive pulses of protons from the AGS will be injected at 29.4 GeV into both rings, captured, and debunched. When a circulating current of about 8 A is accumulated, the stacked beams will be rebunched and accelerated to full energy in approximately one half hour.

ISABELLE MAGNETS

The long acceleration cycle and the storage operating conditions at ISABELLE motivate the use of superconducting magnets. Not only is power consumption reduced, but very high magnetic fields are feasible with this approach. There are approximately 700 dipole and 350 quadrupole magnets, 5 m and 2.5 m long, respectively, in the ISABELLE lattice. They are wound from a braided multifilamentary NbTi conductor. The long "saddle coils" are fabricated by a high pressure molding technique, and clamped firmly on an underlying cylindrical bore tube by a stack of iron laminations, which provides a return path for the magnetic flux and provides mechanical constraint against the forces generated at the magnetic field of 50,000 G and the operating current of 4,000 A. The magnets are cooled by forced circulation of supercritical helium at 3.8K and five atmospheres pressure. Figure 5 shows an isometric view of a pair of assembled dipole magnets in their cryostats.

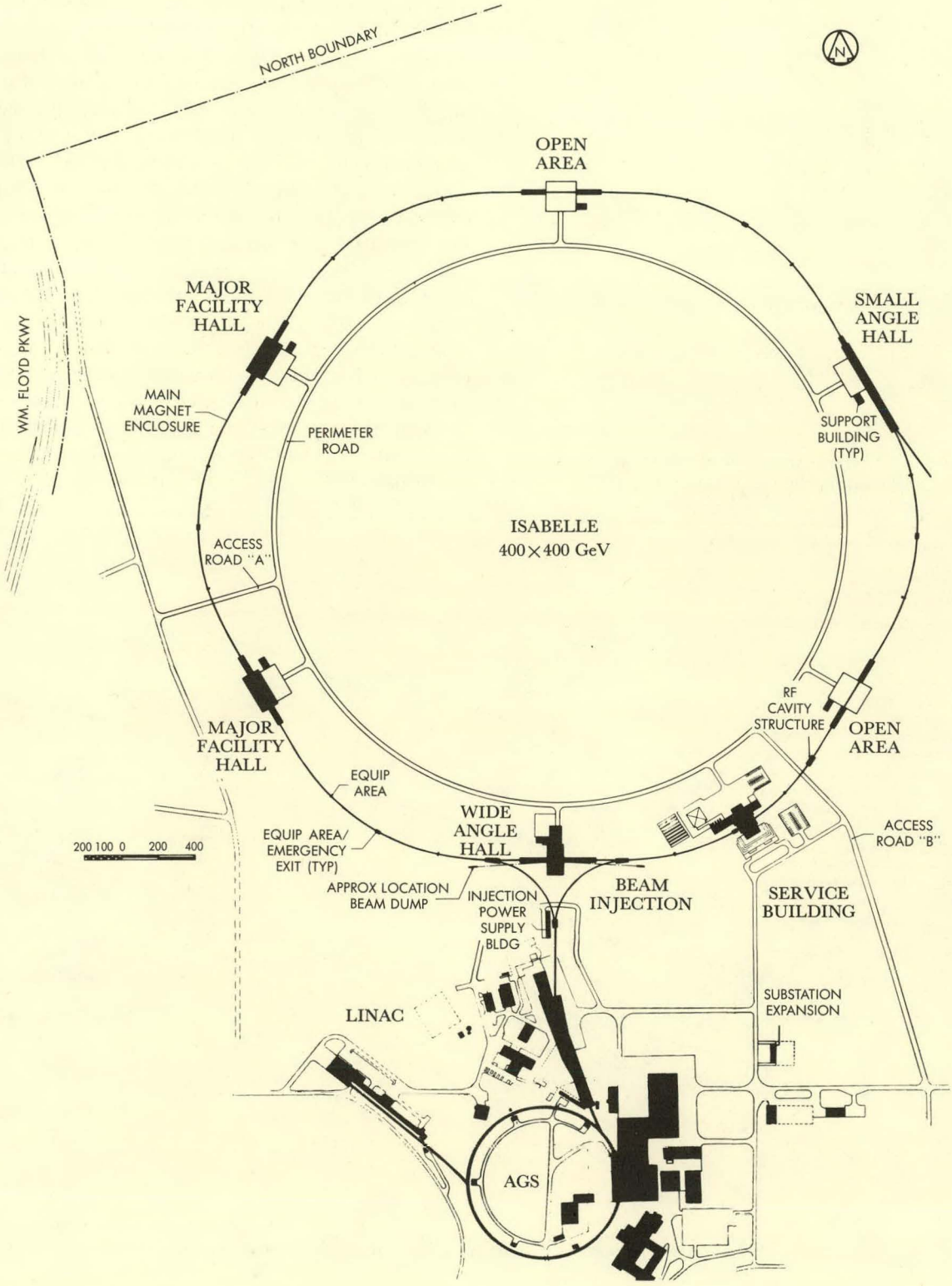

Figure 3. ISABELLE layout at Brookhaven.

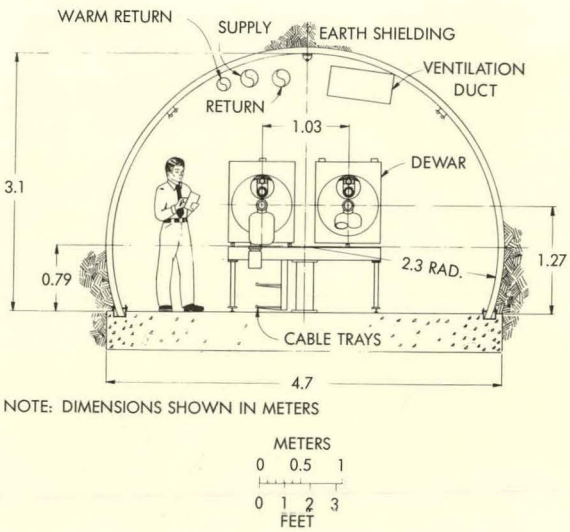

Figure 4. Cross section of the ISABELLE tunnel containing the two magnet rings.

In January of 1979, the first industrially wound pre-production prototype dipole was tested, followed shortly thereafter by a prototype quadrupole magnet. Altogether a dozen prototype magnets were wound by industry during the year, assembled by BNL, and exhaustively tested. As the tests progressed, the coil construction technique was gradually refined to the point where it results in stable magnets meeting the very tight tolerances on magnetic field precision essential in a storage ring. The remaining effort has centered on reaching the design operating field in a relatively modest number of "training" steps; this requirement has necessitated an increased research and development effort which emphasizes the need to understand in detail the mechanical assembly requirements.

As we go to press, final specifications for the initial batch of production quadrupole magnets are completed, with the first units expected in

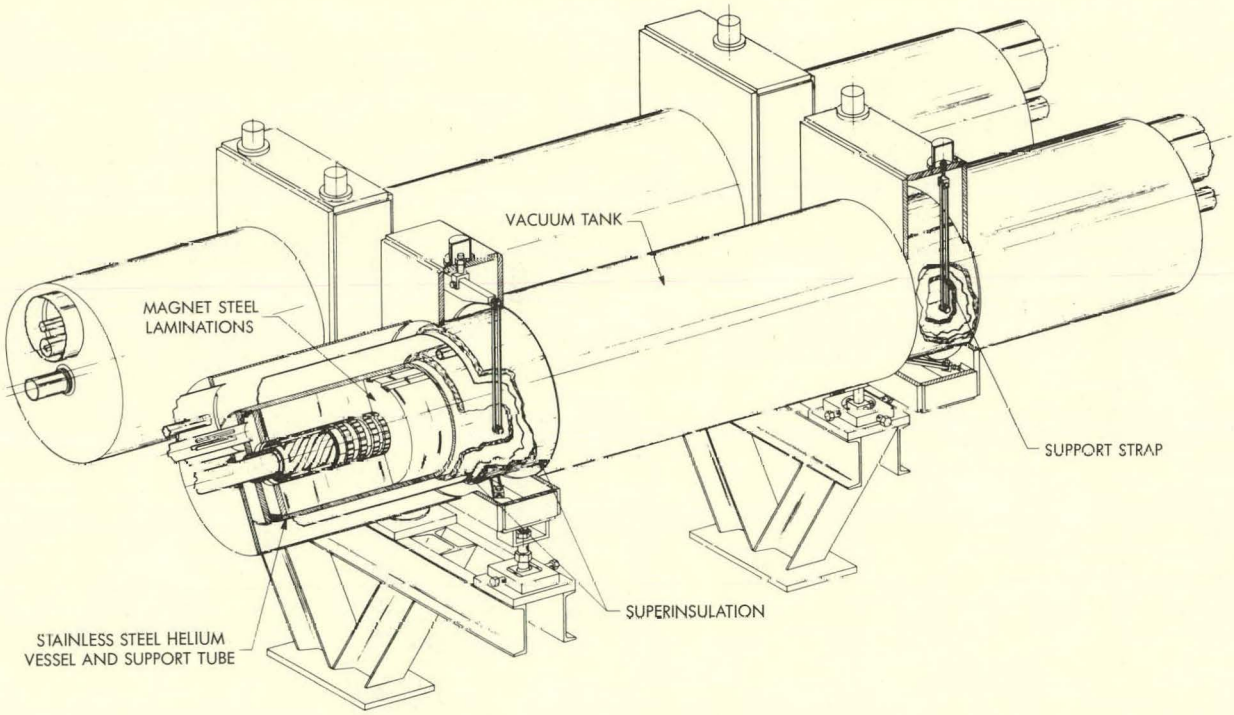

Figure 5. Isometric view of two dipole magnets assembled in their cryostats.

the summer of 1980. The first production dipole should be on hand by the end of the year. Meanwhile, a 45.7 m long tunnel section (Fig. 6) will, when filled with prototype magnets and other components, and refrigerated by the on-hand "R&D Refrigerator," simulate a section of the machine ring under power.

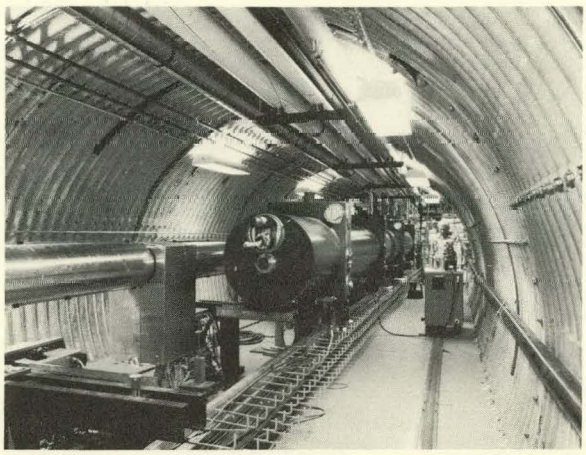

Figure 6. View of ISABELLE test tunnel section.

ISABELLE PROJECT

Administration

J.R. Sanford	Project Head	H. McChesney, Jr.	Head, Administrative Division
K. Johnsen	Deputy Project Head	E.P. Rohrer	Head, Construction Division
H. Hahn	Assistant Project Head	W.J. Willis	Head, Detector Division
J. Spiro	Assistant Project Head	D.H. White	Head, Experimental Areas Division
M.Q. Barton	Head, Accelerator Division	R.W. Young	Safety Officer
R.I. Louttit	Deputy Division Head	M. Shear	Quality Assurance Officer
E.J. Bleser	Head, Magnet Construction Division	E.W. Dexter	Administrative Engineer

ACCELERATOR DIVISION

Theory

M. Cornacchia
E. Courant
J. Herrera
K. Jellett
M. Month*
G. Parsen
C. Pellegrini
J. Poole
M. Puglisi
R. Ruth (part time)
J. Wang

Injection/Ejection

G. Bozoki
J. Claus
H. Foelsch
J. Keohane
P. Montemurro
R. Nawrocky
C. Schmidt
R. Thernn
J. Wilson

Electrical Components

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W. Buxton
R. Edwards
E. Ezura
Y. Farah
R. Frankel
G. Ganetis
S. Giordano
A. Herman
K. Hillman
J. Humphrey
S. Kennell
B. Morris
M. Plotkin
E. Raka
V. Saladino
E. Tiagha
F.G. Tinta
A. Tomasino
J. Votruba
R. Warkentien

*On leave

ACCELERATOR DIVISION (Cont'd)

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J. Bamberger
D. Brown
A. Fresco
A. Schlafke
W. Schneider
A. Werner
D. Weston
K. Wu

Vacuum

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C. Christianson
J. Dovydaitis
C. Foerster
H. Halama
H. Hseuh
P. Stattel

Installation

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J. Cottingham
I. Polk
R. Rosenka
M. Woodle

MAGNET DIVISION

Production

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A. Bertsche
C. Briening
V. Buchanan
J. Cullen
J. Donhowe
D. Gilzinger
R. Hodor
R. Kehl
W. McGahern
R. Migneney
R. Oram
L. Repeta
G. Tanguay
C. Theisen
M. Thomas
W. Velia
A. White

Development

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W. Sampson

Planning & Analysis

P. Dahl
A. Greene
J. Kaugerts
M. Tannenbaum
P. Wanderer
P. Yamin

Testing & Measuring

F. Bock
R. Engelmann
D. Garnder
S. Michaile
K. Robins

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J. Feldman
P. Mohn
M. Schaeffer
R. Taylor

DETECTOR DIVISION

T. Ludlam
V. Polychronakos
J. Renardi

EXPERIMENTAL AREAS DIVISION

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B. Gibbard
P. Gollon (part time)
D. Plows
G. Rabinowitz
E. Rogers
A. Stevens
A. Thorndike
W. Walker

Physics and Chemistry

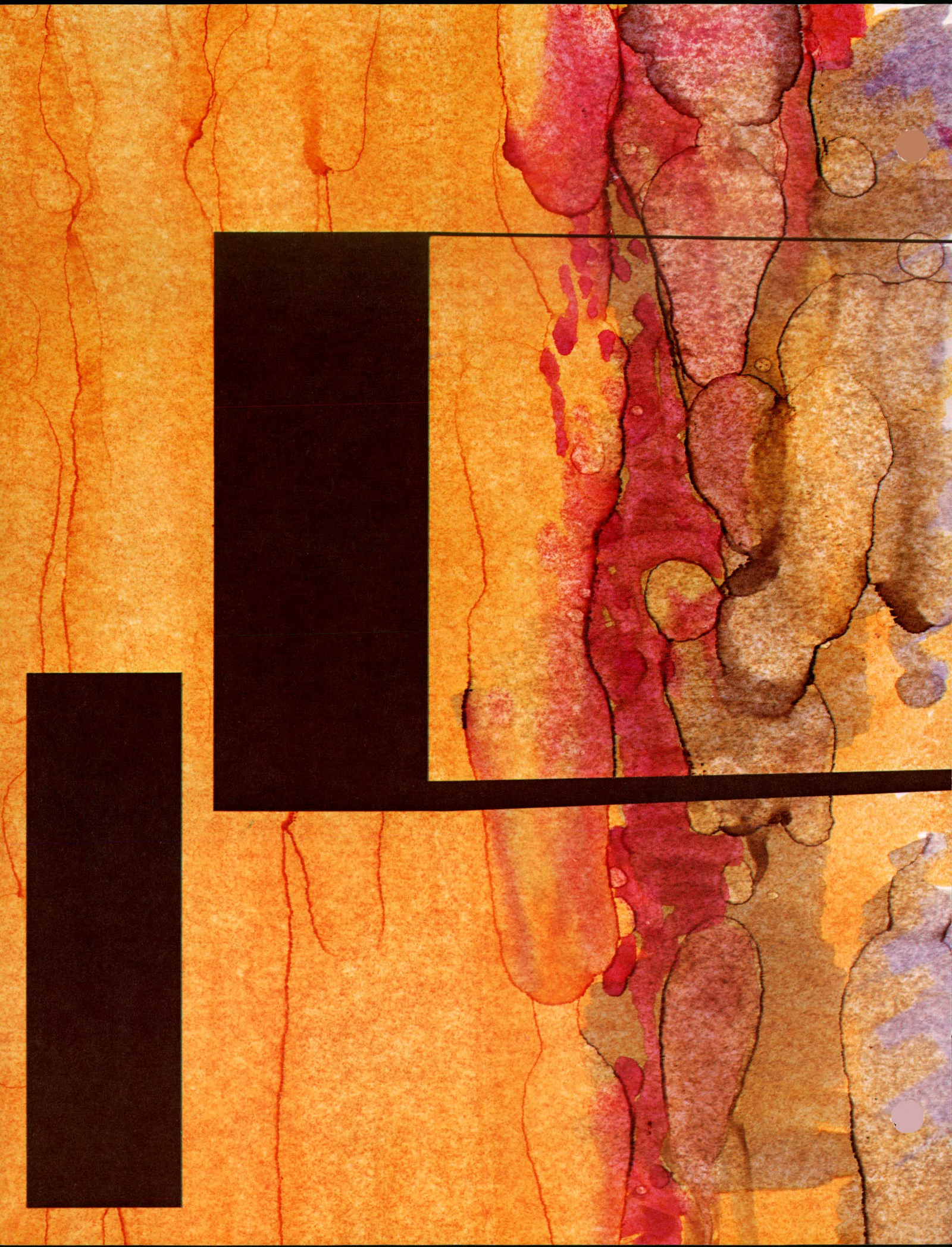
Nuclear Physics

Atomic and Applied Physics

Solid State Physics

National Synchrotron Light Source

Chemistry Department



Physics Department

INTRODUCTION

The Physics Department carries out fundamental research in elementary particle (or high energy), nuclear, solid state, and atomic physics. In each discipline, the experimental program is based in large part on Brookhaven's major facilities. These research facilities provide unique capabilities not only to the BNL staff but also to the national scientific community.

Because research in high energy physics is performed by members of the BNL Physics Department, university users, and members of the Accelerator Department, frequently in teams representing more than one group, it seemed best to report that work in a separate section.

The low and medium energy nuclear physics programs carried out by members of the BNL Physics Department and many university community users address questions of the fundamental nature of the structure and interaction of nuclei and nucleons. Beams from the Tandem Van de Graaff Facility, the High Flux Beam Reactor, and the AGS are used in a variety of experiments to study new phenomena. Heavy-ion beams are used for diverse investigations of the reaction mechanisms of heavy ions and the forces between them, the production of the γ-decay of nuclei in states of very high angular momentum, the existence and production of nuclei way off stability, and nuclear electromagnetic properties such as γ-transition rates and static moments. Reactor neutrons are used to perform detailed studies of the structure and dynamics of nuclei utilizing the (n, γ) reaction, as well as for studies of resonance parameters and neutron cross section of interest to applied fields. The AGS nuclear physics program is presently concerned with the spectroscopy of hypernuclei — nuclei which contain a Λ or Σ hyperon. The Nuclear Theory group has a close interaction with the experimental groups, as well as a wide-ranging program in many exciting topics in nuclear theory. The Laboratory thus provides an opportunity for a very broad program of fundamental nuclear physics. In addition, the Tandem Van de Graaff is used for investigations of the atomic physics of highly excited and stripped atoms.

The solid state research effort is concerned with the cohesive forces that bind atoms together to form the various phases of condensed matter. The facilities such as the High Flux Beam Reactor and the National Synchrotron Light Source, now under construction, provide unique probes for studying the properties of solids on the atomic scale. Particular emphasis is placed on the studies of materials exhibiting phase transformations where a delicate balance of the interatomic forces exists such that a slight change in the external environment (such as temperature or pressure) can produce a significant modification of the atomic arrangement. These studies provide a means of testing the various theories of phase transformations and lead, in many cases, to the prediction of interesting new types of solid structures. Other studies try to unravel the properties of "real" solids, i.e., solids in which the symmetrical arrangement of atoms is disturbed by impurities and crystallographic defects. The resulting changes in the interatomic forces and properties are not always predictable and the experimental results provide a phenomenological understanding of imperfect solids. A further region of growing interest is the study of surfaces. One intriguing problem arising in this field is how the interatomic forces and their arrangement vary when atoms are bound on one side only. Frequently, a different atomic species can be attached to a surface and a new type of atomic arrangement is obtained.

At the end of each section a selected list of publications is appended. These lists represent only a small fraction of the papers published during the year.

Nuclear Physics

The two major facilities for experimental nuclear physics research at BNL are the Tandem Van de Graaff accelerator and the High Flux Beam Reactor (HFBR). In addition, research in hypernuclear physics is conducted at the Brookhaven AGS, using secondary beams of kaons. The nuclear theory group supports the experimental effort in both heavy ion and medium energy physics as well as doing research on other topics of current interest. We present a brief discussion of the highlights of these diverse programs.

THE BNL TANDEM ACCELERATOR

The Tandem Van de Graaff Facility accelerates a number of light and heavy ion beams with good energy resolution over a range of energies. It is utilized by researchers from BNL and numerous other laboratories and universities to conduct basic research in nuclear, solid state, and atomic physics. As new areas of research open up, the Tandem has been continuously upgraded. In the past year, a number of improvements have been made. A helium-jet system for the study of short-lived radioactivities was completed. The radioactive atoms, produced by bombardment of a target in a gas cell, are swept out of the cell by a helium-aerosol mixture to a tape where the radioactivity is recorded. Beta rays, gamma rays, or delayed protons or alphas can be measured.

A new spectrometer system for high energy γ rays is now operational. It is based on a large NaI crystal, with surrounding photomultiplier tubes. Measurements of capture reactions such as $^{11}B(p, \gamma)$ have shown that the system has a high resolution, typically better than 3% for a 20 MeV γ ray.

A time-of-flight scattering chamber is now in general use. Time resolutions as good as 220 psec have been observed with two-detector systems. A large ion chamber for the measurement of heavy ion energies as well as energy loss has now been incorporated with the time-of-flight system.

The EMS (energy mass selector) system has been considerably improved by augmenting the solid angle to 6 msr, an increase of five times. The EMS now eliminates all of the particles at 0° having the beam energy. By installing a transmission ionization chamber at the end of the EMS, in anticoincidence with the detector, alpha spectra free of background can be obtained. The EMS permits the measurement of evaporation residues as a function of energy, angle, and velocity window through the device, in order to obtain total fusion cross sections.

There has been considerable progress on the design and construction of an ultrasensitive TV imaging system for the Tandem. Such a device detects multiple events simultaneously in an X, Y plane and provides an energy measurement and digital coordinates for each event. This will be very useful for Coulomb explosion studies of molecular structure and future track or streamer chamber measurements of multiple fragmentation of nuclei.

A proposal to DOE for a cyclotron addition to the Tandem was completed and submitted to the Nuclear Sciences Advisory Committee. In this proposal, bunched heavy ion beams from the Tandem are injected into the cyclotron, where they are further accelerated and returned to the present target areas. At its highest energy, the variable energy system will produce beams of 150 MeV/amu oxygen and 16 MeV/amu uranium. Such an improved facility would greatly expand the range of physics problems which can be addressed at the Tandem.

HEAVY ION EXPERIMENTS AT THE TANDEM

Nuclear physics research with heavy ions is an area of broad interest. Due to the composite nature of the projectile, nuclear reactions induced by heavy ions can involve the transfer of large amounts of angular momentum and energy. By varying the kinematical conditions, one can study a variety of phenomena: "gentle" processes involving grazing collisions (elastic and

inelastic scattering, few particle transfer reactions), or deep inelastic and fusion processes arising from more central collisions. A compound nucleus formed by the fusion of two heavy ions is a very neutron-deficient system at high excitation energy and high spin. Many states of high spin in known nuclei, and also new nuclei not accessible to other reactions, have been observed in heavy ion reactions.

In the following paragraphs, we review some of the recent experimental results from the Tandem.

Spin-flip in Heavy Ion Reactions

The first observation of a heavy ion spin-orbit interaction was recently made at the Tandem. Inelastic scattering of ^{13}C from ^{24}Mg at 35 MeV was used to populate the first excited state of ^{24}Mg. Gamma rays from the decay of this state are not emitted perpendicular to the reaction plane unless the ^{13}C undergoes spin flip. Such a spin flip can be seen in a coincidence measurement between the outgoing ^{13}C and the γ ray emitted from the excited ^{24}Mg. A large amount of spin flip was observed at certain angles, indicating a significantly larger spin-orbit potential than had been suggested theoretically.

Elastic Scattering at Large Angles

Several years ago, striking enhancements were found in heavy ion elastic scattering at θ_{cm} = 180°. This was unexpected, since it was assumed that the absorptive potential for heavy ions would be strong enough to lead to a sharp decrease of scattering at back angles. Instead, the data gave evidence for weaker absorption in the crucial surface region, leading to the possibility of a resonance in a particular grazing partial wave.

In the last year, several new experiments have been done at the Tandem which clarify the situation somewhat. A variable energy ^{28}Si beam was used to bombard ^{16}O and ^{12}C targets, and the resulting excitation functions at 90° were found to oscillate smoothly in energy with a period equal to that for the same reactions at 180°. However, the 180° and 90° data were *anticorrelated.* Some of the data are shown in Fig. 1. These broad structures are also seen in inelastic scattering. These data place strong constraints on the theoretical models invoked to explain structures in excitation functions. One theory attributes these structures to resonances associated with special levels of the compound system, whereas another approach suggests that they are of dynamical origin, arising from the surface transparency of the optical potential. A comparison of the data on the systems ^{16}O + $^{28,29,30}Si$ tends to support the latter explanation, since a very similar gross structure (although damped in $^{29,30}Si$) is seen in the three cases, although the compound nuclear levels are quite different. Studies of the angular cross correlations of these structures in several excitation functions, now under way, should enable one to distinguish between resonances and statistical fluctuations.

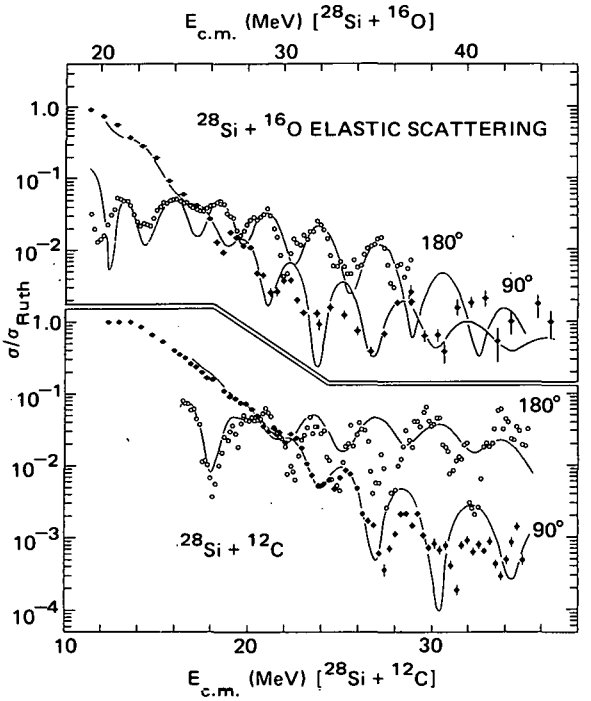


Figure 1. Excitation functions at 90° and 180° for the elastic scattering of ^{28}Si + ^{16}O and ^{28}Si + ^{12}C. The solid curves are the result of optical model calculations including a parity dependent term in the potential [S. Kubono, P.D. Bond, D. Horn and C.E. Thorn, *Phys. Lett.* **84B,** 408 (1979)].

High Spin States in Nuclei

Heavy ion reactions populate a rich variety of nuclear states and afford unique methods for investigating many aspects of nuclear structure. For instance, fusion reactions, followed by particle evaporation, lead to high spin states in the

residual nuclei. The γ-ray spectroscopy of such nuclei has been intensively studied at the Tandem. Many other related studies of nuclear structure have recently been carried out at BNL. These include i) accurate measurements of electromagnetic transition probabilities and quadrupole moments via Coulomb excitation; ii) magnetic g-factor measurements by the method of perturbed angular correlations, using the strong spin alignments resulting from heavy ion fusion; iii) radiative capture of heavy ions, which enables one to study very special nuclear states often inaccessible to other processes.

Recent BNL work on high spin states has concentrated on the region near the N=82 shell closure. This region is not well understood theoretically, and is proving to be a rich source of information on nuclear structure. We discuss the particular example shown in Fig. 2 of high spin states in ^{150}Gd, which were populated via the ^{124}Sn (^{30}Si, 4n) reaction at 135 MeV. The low-lying states ($I \leq 18$) are similar to those observed in other N=86 even-even nuclei. Starting with the 21^- state, we see a quasi-band structure up to 27^-. These states may be interpreted as couplings of the 9^- or 10^+ proton configurations (observed in ^{146}Gd) to the low-lying positive and negative parity four neutron configurations (ν^4) in ^{150}Gd. The states of highest spin (30^+ to 36^+) are suggestive of the coupling of (ν^4) 20^+ to the 10^+ to 16^+ proton configurations. Even for such high spins, relatively pure and near spherical shell model states may well remain the dominant mode of excitation.

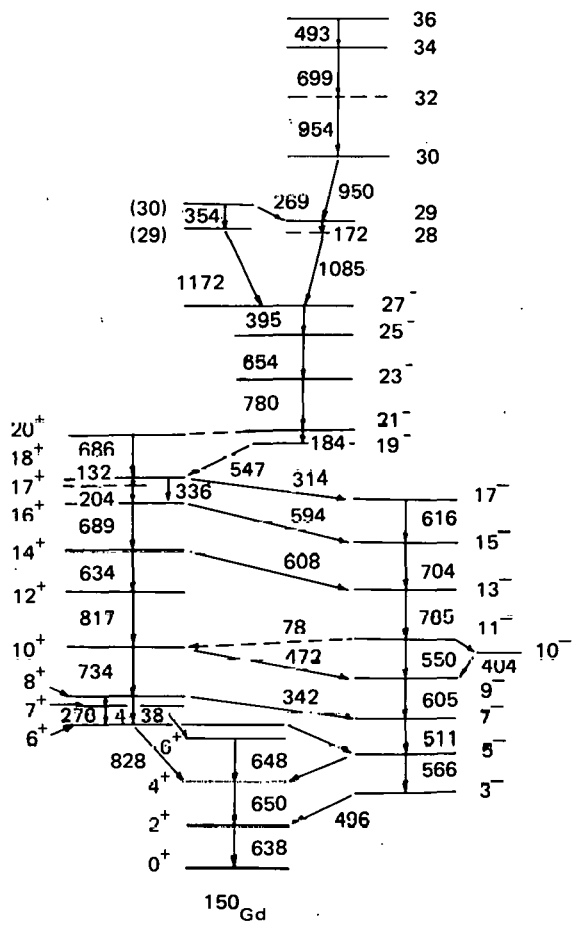


Figure 2. The high spin structure of the N = 86 nucleus ^{150}Gd, as studied by means of the ^{124}Sn(^{30}Si,4n) reaction (C. Baktash, E. der Mateosian, O.C. Kistner, A.W. Sunyar, D. Horn and C.J. Lister, to be published).

Structure of Odd-Odd Transitional Nuclei

Nuclei having an odd number of both neutrons and protons have received less attention than even-even systems, perhaps because their structure, particularly for transitional nuclei, was expected to be complicated. These nuclei have recently been studied by a group of collaborators from BNL and the Argentine Atomic Energy Commission, as part of a program of scientific cooperation with Latin America. Using heavy ion-induced reactions, the nuclei ^{74,76}Br, ^{78}Rb, and ^{190,192,200}Tl were investigated. The level schemes show strikingly simple and systematic band structures with characteristic level "staggering", i.e., alternating small and large level spacings. A theoretical description of these results was developed, based on the coupling of two quasi-particles to a rotor. In this model, the level staggering arises from the even-even core angular momentum, which jumps by two units for every second state while the quasiparticles realign so as to produce differences of one unit of spin between successive members of the band. The model also includes the effect of the Coriolis interaction on the intrinsic motion and the residual quasi-particle force.

Nuclei off the Line of Stability

A number of new neutron deficient radioactive isotopes in the $A \approx 80$ region were found at the Tandem, using the new helium jet and tape-

transport system, together with Ge(Li) γ-ray detectors and β-ray detectors to obtain the decay schemes and masses. Targets of ^{58,60}Ni were bombarded with ^{24,25}Mg, ^{27}Al, ^{28,29}Si, and ^{32}S beams to produce the new species ^{79}Sr, ^{80,81,82}Y, and ^{83,84}Zr. As well as enlarging the table of isotopes, the masses and spectroscopic features of these nuclei can be used to test theoretical predictions.

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P.D. BOND, M.J. LEVINE, D.J. PISANO, C.E. THORN, AND L.L. LEE, Jr. L=1 single-proton pickup reactions on ^{40}Ca. *Phys. Rev.* **C19,** 2160-2166 (1979).

W. DÜNNWEBER, P.D. BOND, C. CHASMAN, AND S. KUBONO. Observation of spin-flip in ^{13}C + ^{24}Mg inelastic scattering. *Phys. Rev. Lett.* **43,** 1642-1645 (1979).

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M.B. GOLIN, AND S. KUBONO. Spin-orbit potential for the ^{19}F + ^{28}Si elastic scattering. *Phys. Rev.* **C20,** 1347 (1979).

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THE HIGH FLUX BEAM REACTOR

The High Flux Beam Reactor (HFBR) at Brookhaven provides a variety of neutron beams for solid state and nuclear structure studies. The beams used for nuclear measurements at the HFBR consist of both pulsed beams for time-of-flight measurements and continuous beams filtered through various materials or diffracted from crystal planes. Both "white" and monoenergetic beams are available with energies up to 24 keV. These beams are used for (n,γ) reaction studies, production of fission products, and cross section measurements.

The (n,γ) reaction is capable of populating a wide variety of final nuclear configurations, and thus provides a powerful tool in nuclear structure studies. Coincidence and angular correlation measurements of the resulting γ-ray cascade can provide spin and parity assignments for excited levels. Using the technique of average resonance capture, a non-selective reaction, a complete set of low spin states can be populated. The completeness of the level schemes is an important feature, which enables one to test nuclear models in great detail.

During 1979, the on-line isotope separator TRISTAN was installed at the reactor. This facility provides beams of fragments resulting from the fission of ^{235}U. These neutron-rich nuclides are used for studies of delayed neutron emission and systems far off the valley of stability. On-going developments in ion source technology show promise of enhancing the capabilities of TRISTAN. The goals of this effort are to produce elements such as molybdenum, zirconium, and niobium which are not obtainable with a plasma-type ion source, and to make use of the high HFBR flux through an internal target.

In the next few sections, we review some of the highlights of the research program at the HFBR.

Tests of the Interacting Boson Model for Odd Mass Nuclei

An important advance in nuclear structure physics has been the development of the Interacting Boson Model (IBM). This model explains a number of nuclear properties in terms of *pairs* of nucleons ("bosons"), rather than individual neutrons and protons. This approach allows a unified description of nuclei which have very different properties (rotational or vibrational, for instance). Applications of the IBM to even nuclei led to the recognition of three natural limiting cases of dynamical symmetry. Data on the nucleus ^{196}Pt, obtained by a BNL-Grenoble collaboration in 1977, established the existence of one of these limits, the 0(6) symmetry, which was previously unknown.

Recent work at BNL has shown that the IBM is also successful for odd nuclei. Studies with the (n,γ) reaction have isolated the full sequence of low spin states associated with the unique parity orbit in ^{109}Pd. The particle-rotor model, which was the generally accepted theoretical approach to such level schemes, was found to fail in this case, while the IBM gave an excellent description of the data. This first test of the IBM for odd nuclei suggests an extensive and rich testing ground for the model's predictions.

Strength Functions for Radiative Transitions

Discrete resonance neutron capture can provide the most reliable parameters for the calculation of radiative strength functions, in particular for E1 and M1 transitions. There has been considerable recent interest in these strengths, as revealed through (n,γ), (γ,n) and (γ,γ') measurements, a number of which were performed by the BNL fast chopper group. The M1 strengths tend to be equal to or larger than single particle estimates, indicative of a collective enhancement near the neutron binding energy. The E1 strengths at energies above the dipole peak are systematically less than those expected on the basis of the standard Lorentzian shape for the giant dipole resonance. These results are of considerable interest for the theory of giant resonances.

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Medium Energy Physics

The major thrust of the intermediate energy physics program at BNL is the study of nuclear structure by using energetic elementary particles as probes. Proton projectiles have been used at the High Resolution Spectrometer (HRS) at the Los Alamos Meson Physics Facility (LAMPF), in collaboration with several other groups. This work is an extension of a series of experiments started a number of years ago at the BNL Cosmotron. The intense separated kaon (K^-) beam available at the BNL Alternating Gradient Synchrotron (AGS) has been used to study the formation of "hypernuclei", new nuclear species created by transforming one of the constituent nucleons into a lambda hyperon (Λ) via the (K^-, π^-) reaction.

A magnetic spectrometer for the detection of the outgoing pions (π) in the (K^-, π^-) process, and also suitable for $K^\pm$ elastic and inelastic scattering measurements, is in operation at the AGS. The spectrometer can be rotated in order to measure the angular distribution for the outgoing particle, which is essential for spin assignments. This feature also gives us access to the region of higher momentum transfers, where high spin states of the hypernucleus can be formed. The BNL facility is unique in this respect.

A program for making improvements in the spectrometer is underway, with the aim of augmenting the event rate substantially by increasing the kaon flux incident on the target and also the solid angle of the pion spectrometer. The larger event rate will make it possible to detect hypernuclear γ rays in coincidence with pions, thereby obtaining more spectroscopic information.

A workshop group was formed for the purpose of designing a new high intensity kaon facility at BNL. The workship meetings have been attended by a number of potential users from the University community, who are also participating in the design. Such a facility would open up a new realm of hypernuclear structure physics, since many types of experiments with cross section of the order of 1 μb/sr would become feasible.

We now discuss the highlights of the experimental medium energy program during the past year.

Quasielastic Proton Scattering

The emission of protons from various nuclear targets under bombardment from 800 MeV protons was studied by the BNL group in a collaborative effort at LAMPF. At such high energies, coherent effects no longer dominate the cross section, and a nucleon-nucleus collision can usefully be treated as a series of nucleon-nucleon encounters. If a single collision takes place and the two nucleons leave the nucleus, the process is called "quasielastic". If this collision produces a pion, the reaction can be described as a quasi-two-body process involving the formation of a "Δ" isobar (pion-nucleon resonance). In the present experiment, differential cross sections as a function of the proton's angle and momentum were obtained. These were analyzed by means of the Distorted Wave Impulse Approximation (DWIA) which describes initial and final state interactions via a complex distorting potential. The data also show structure for kinematical conditions corresponding to nucleon scattering from groups of two and four particles, which is of interest from the point of view of the cluster model of nuclei.

Hypernuclear Physics

A study of the hypernucleus ${}^{12}_{\Lambda}C$ with improved resolution was completed at the AGS, using the strangeness exchange reaction ${}^{12}C(K^-, \pi^-){}^{12}_{\Lambda}C$. For the first time, angular distributions to various final states of ${}^{12}_{\Lambda}C$ were measured, leading to several spin-parity (J^π) assignments.

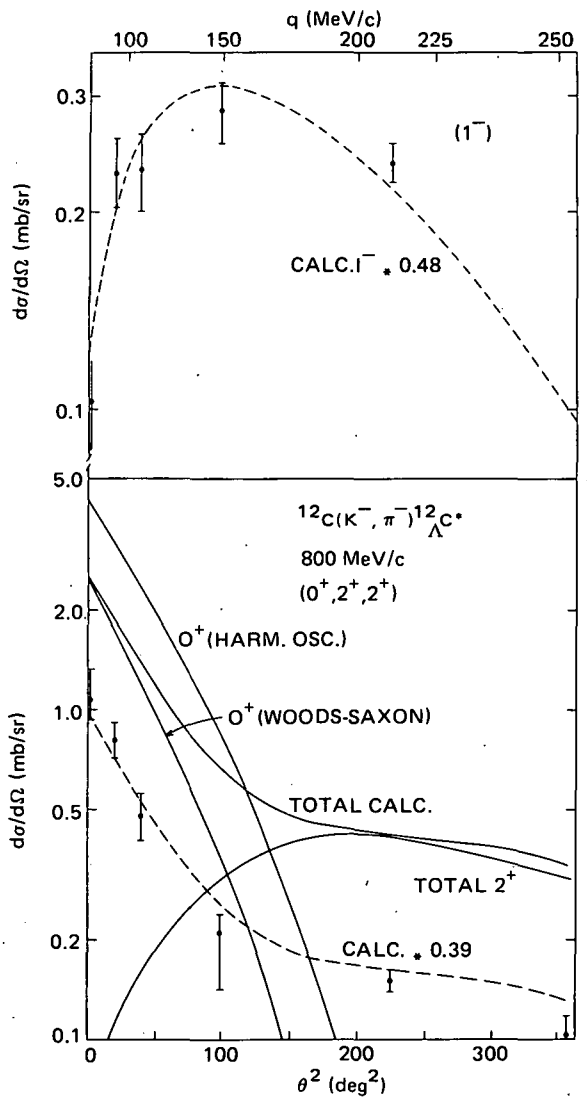

Figure 3. Experimental and theoretical angular distributions for the hypernucleus formation reaction $^{12}C(K^-,\pi^-)^{12}_{\Lambda}C$. The ground state distribution is shown at the top; excited states with $J^{\pi} = 0^+,2^+$ are at the bottom [R. Chrien *et al., Phys. Lett.* **89B,** 31 (1979); C. Dover, A. Gal, G.E. Walker and R.H. Dalitz, *Phys. Lett.* **89B,** 26 (1979)].

Previous experiments at $\theta = 0°$ were mostly sensitive to $J^{\pi} = 0^+$ states. The data are shown in Fig. 3, together with the results of theoretical calculations based on a simple Λ particle-neutron hole description of the states of $^{12}_{\Lambda}C$. From these data, the ground state of $^{12}_{\Lambda}C$ is assigned spin-parity 1^-, while the shoulder in the angular distribution to the group of states at about 11 MeV of excitation energy indicates the presence of both 0^+ and 2^+ components. The detailed analysis of this and other similar data provides information on the quasiparticle properties of a Λ particle in the nuclear medium (central well depth, spin-orbit potential) as well as the residual interaction of a Λ with a nucleon. We thus obtain information on baryon-baryon forces not obtainable in experiments with non-strange probes.

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Nuclear Theory

The nuclear theory group is engaged in research on a wide range of topics in heavy ion physics, intermediate energy and occasionally particle physics, nuclear structure, weak interactions, and nuclear astrophysics. There are frequent collaborations with theoreticians at universities and other national laboratories. The effort is divided between fundamental studies and phenomenological analyses. Close links exist between the theory group and experimental groups in low, intermediate, and occasionally high energy physics. Part of the group has played an important role in the conceptual and practical design for the heavy-ion cyclotron booster now proposed for construction at BNL, in particular the design of the isochronous magnetic field and the analysis of the particle beam dynamics. Another part of the group has been involved in the preparation of a proposal for an improved kaon physics facility at the AGS, concentrating on the physics justification for a new kaon beam.

We now discuss selected highlights of the past year.

Large Angle Heavy Ion Scattering

The search continues for a comprehensive theoretical description of the phenomenon seen in large angle elastic scattering for α-like systems such as $^{16}O + ^{28}Si$, $^{12}C + ^{32}S$, etc. The experimental signature for this is a strong oscillatory rise in the elastic cross section near 180° and related behavior in certain inelastic excitations. There is also a periodic structure, reminiscent of resonance behavior, seen in the excitation functions. The key theoretical question is whether this is truly a resonance phenomenon, corresponding to molecular orbiting of the ions, or whether this behavior can be incorporated in a reasonably energy-independent local optical potential. Recently, attention was focused on the $^{16}O + ^{28}Si$ data at 21 MeV, just above the Coulomb barrier. Careful optical model fits to the data were done, using the values of the real potential in the sensitive surface region as search variables rather than the standard depth, radius, and diffuseness parameters. A surface transparent absorptive potential is used. The heavy ion real potential thus obtained exhibits significant repulsion at small interaction distances and a second attractive minimum at fairly large distances. Whether these remarkable features recur in other dynamical situations is now being investigated.

Shell Model Studies of Nuclear Structure and Weak Interactions

Nuclear structure studies of p-shell and light sd-shell nuclei have been carried out using a general shell model program. This code uses a basis of states classified according to the group SU(3) and allows valence nucleons to populate the first four major shells. Attention has been focused on transitions in which there is a change of parity, the experimental data coming from measurements of γ decay lifetimes and mixing ratios, first forbidden β-decay, and inelastic scattering determinations of transverse form factors. The successful description of these processes in the shell model gives a much more stringent test of the wave functions than would a fit to the energy spectrum alone. Another important application of the SU(3) shell model is to parity mixing experiments in nuclei such as ^{10}B, ^{18}F, ^{19}F, and ^{21}Ne. Parity non-conserving interactions arising from pi and rho meson exchange give rise to such mixing. Similar matrix elements arise in $0^- \leftrightarrow 0^+$ β-decay and μ-capture in connection with the contribution of mesonic exchange currents to the axial vector current. The emphasis here has been on the description of a wide variety of physical processes within a consistent shell model framework, including processes which depend on rather delicate features of nuclear wave functions (admixtures of small components to a dominant representation, relative phases, etc.)

Kaon-Nuclear Physics

Kaon physics is a developing area. Pioneering experiments at CERN in Geneva and at BNL have provided glimpses of the spectroscopy of a

strange baryon (Λ or Σ) embedded in the nucleus, via the (K^-, π^-) strangeness exchange reaction. There are as yet very little data on other kaon-induced elastic and inelastic processes on nuclei. The effort of the theory group has been directed towards the exploration of possible avenues for future experiments as well as the interpretation of the recent hypernuclear data. It was suggested that K^+ elastic, inelastic, and charge exchange scattering on nuclei would be a fruitful area for study. Since the elementary K^+-nucleon interaction is rather weak, the K^+-nucleus reaction mechanism should be particularly simple at low energies. Interesting modes of nuclear motion such as high spin unnatural parity states, maximum isospin components of giant dipole resonances, and collective monopole and quadrupole resonances could be investigated with K^+ beams.

A preliminary study of $\Lambda\Lambda$ and Ξ^- double-hypernucleus formation via the (K^-,K^+) reaction indicated summed cross sections of several microbarns. Such cross sections may be measurable if a new kaon facility becomes a reality. This would open the new domain of doubly strange hypernuclei. It has also been suggested that the (π^+,K^+) reaction on nuclear targets could be used to produce hypernuclei. The production mechanism involves high momentum transfers, even at $\theta = 0°$, so high spin states of the residual hypernucleus will be preferentially excited. This mechanism would then carry special advantages, complementary to other ways of producing hypernuclei. Calculations indicate cross sections to particular Λ particle-neutron hole states of 10-20 μb/sr at 0°, which is measurable with available pion beam intensities at the AGS. This promising area of hypernuclear spectroscopy (high spin "stretch" states) is as yet totally unexplored experimentally.

Another topic of great current interest is the existence of relatively long-lived states of Σ hypernuclei. Preliminary evidence for Σ excitations of width $\Gamma \approx 10$ MeV has been presented by the CERN group. Nuclear matter estimates based on the conversion process $\Sigma^- p \rightarrow \Lambda n$ predict widths of at least $\Gamma \approx 20$ MeV. The BNL-Hebrew University collaboration suggested a mechanism for the quenching of the Σ width in light nuclei, based on the observation that the $\Sigma \rightarrow \Lambda$ conversion amplitude is strongly dependent on spin and isospin. Narrow Σ widths were unanticipated, and hence this problem poses an exciting theoretical challenge.

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Atomic and Applied Physics

In atomic physics an active program of beam-foil spectroscopy (BFS) designed to study properties of selected highly-ionized elements in the extreme ultraviolet (EUV) was continued using a 2.2-m grazing-incidence spectrometer and beams of heavy ions from the BNL Tandem Van de Graaff Facility. During the year the operation of the spectrometer was improved significantly and extensive measurements were made on Fe, Cr, Ni, and I for the wavelength region between 5 and 50 nm.

The detection system of the spectrometer was improved by use of a microchannel plate with a position-sensitive read-out. Charge produced on a resistive sheet at the exit of the channel plate produces voltage pulses at the ends of the sheet whose pulse height depends on the position of the event on the surface of the microchannel plate. Analog dividers are then used to process the two pulses to produce a signal indicative of the position of the event on the channel plate. This detection system permits the simultaneous acquisition of data over a span of 6 nm with a resolution of 0.08 nm and with a photon detection efficiency comparable to that of an ordinary Channeltron detector. It is now possible with this system to attain spectra with better resolution and statistics and to measure lifetimes with better evaluation of backgrounds in less time than with the single Channeltron used previously.

The experimental program concentrated on two types of experiments. One of these was the study of ions of particularly simple configurations where experimental results can be compared with the results of theoretical calculations that are expected to be very reliable. The other type of experiment deals with the measurement of spectra and lifetimes of resonance lines of elements that are expected to be present as contaminants in tokamak plasmas because of their use as fabrication materials in the tokamak vacuum vessel.

The study of the resonance lines in copper- and zinc-like iodine falls into the first category. Experiments on these sequences were done elsewhere as far as Kr. The values of wavelengths and lifetimes found for the 3s-3p resonance transitions in Kr were shown to be in good agreement with theory if careful attention was paid to the contributions of cascades to the observed decay curves of the resonance lines. The present measurements for the 4s-4p transitions in I carry the work on the lifetimes of the copper-like sequence to the heaviest element yet considered. Careful measurements of the wavelengths of these lines were made, as well as those of the low-lying cascade transitions. The agreement with theory seems good, although there are rather prominent satellite lines which are not yet understood. The agreement of the lifetimes with theory is not as good. There is a rather large discrepancy for the $^1/_2$-$^3/_2$ transition, but good agreement for the ½-½ case. The discrepancy is attributed to the presence of a short-lived cascade which is particularly awkward to handle in the analysis.

Stainless steel is used extensively in the fabrication of tokamak vacuum vessels. This means that the elements that comprise stainless steel, such as Fe, Cr, and Ni, will be present in a tokamak plasma in highly ionized states. Detailed knowledge of the spectra and lifetimes of the resonance lines of these elements are thus necessary for use in energy loss calculations and interpretation of the EUV spectra observed in the tokamak. BFS studies were made with beams of the elements Fe, Cr, and Ni with energies between 20 and 220 MeV. This energy span permitted observation of a wide range of charge states; e.g., for Fe the range was from about Fe XI to Fe XXI. Spectral measurements covered the range from 5 to 50 nm. Lifetimes were also measured for several resonance lines in Fe and Ni. The detailed analysis of the data with comparison to other plasma sources has just begun. (With J.L. Cecchi, Princeton University Plasma Physics Laboratory; T.H. Kruse, Rutgers University; J.O. Ekberg, University of Lund; and E. Träbert, University of Oxford.)

The electron impact excitation and ionization of heavy ions are processes of great importance

in plasma with heavy element impurities. The cross sections and mechanisms can be studied in an elegant manner by crossing or merging an electron beam with the heavy ion beams from the BNL Tandem Van de Graaff Facility. As an example of the scope of experiments that could be carried out consider the case of Fe, an important factor in both astrophysical and tokamak plasmas. The most probable ionization states that can be produced go from Fe X at an energy of 10 MeV to Fe XXII at 220 MeV. It is thus feasible to produce and study more than half the total number of ionization states possible for iron. Such an experimental facility has not been available anywhere in the world previously, and only at Oak Ridge is there another active attempt to fabricate the required apparatus.

Calculations have been made of estimated interaction rates for a typical case; the intersection of an approximately 1A 4keV electron beam with a 20 nA 200 MeV Fe XIX beam. An estimated rate of 2.2 sec^{-1} is found, which is excellent for experiments of this genre.

Detailed design of the apparatus was undertaken during the first part of the year. The various components include a support stand for the high power electron gun, interaction chamber, beam charge state purifier before the interaction chamber, beam charge state analyzer after the interaction chamber, and vacuum pump ports. Many of the power supplies and vacuum pumps that will be needed have been ordered and will be available for assembly during FY 1980.

In the applied physics program the most advanced techniques available from nuclear and atomic physics are brought to bear on the sensitive measurement of the spatial distribution and bulk concentrations of major, minor, and trace elements and stable isotopes in a variety of samples. The methods developed in the work make possible experiments which cannot be carried out by conventional methods of analysis.

The basic experimental facility is the BNL 3.5-MV Van de Graaff accelerator. Application of these methods to problems in various fields of interest such as energy, bio-medical, materials sciences, environmental, etc. is done in collaboration with scientists from a variety of institutions.

During the year work was completed on the fabrication of a microbeam system using an electrostatic quadrupole lens mounted on an airbag suspension system to reduce the problems of vibration. This will be a very useful device for a variety of experiments in future years.

Experiments using a variety of methods were carried out on the following subjects: a) deuterium detection by use of the $D(T,n)^4He$ reaction, b) analysis of coal samples by Rutherford backscattering (RBS) and proton induced x-ray emission (PIXE), c) measurement of chlorine concentration in thermally grown SiO_2 layers on silicon by RBS, d) determination of fluorine by inelastic proton scattering, e) measurements of trace element concentrations in scoliotic tissues with the proton microprobe, f) study of the relationship between zinc and tissue mineralization with the proton microprobe, and g) the determination of lithium in biological samples by use of the $^6Li(n,\alpha)^3H$ reaction.

These examples demonstrate the applicability of the nuclear analytical methods to measurements in a diverse group of scientific fields. It is expected that they will gain in importance in future years and be a required facility for any well equipped laboratory.

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Solid State Physics

INTRODUCTION

The main goal of the solid state physics research effort is to understand the interatomic forces that bind atoms together to form the various phases of condensed matter. These forces are modified by variations in external parameters such as temperature and pressure, or by introducing defects and disorder into the lattice. Brookhaven possesses several facilities which provide unique probes for studies of these forces. The primary tool is the High Flux Beam Reactor (HFBR) which provides an intense beam of low energy neutrons for studies of the structure and dynamics of condensed matter. Several irradiation facilities are also available to investigate the nature of defects in solids. Under construction is the National Synchrotron Light Source (NSLS) which will provide intense beams of tunable x rays and ultraviolet radiation. These probes will complement the existing techniques in the studies of the atomic and electronic structures of solids and surfaces.

NEUTRON SCATTERING STUDIES

Thermal neutrons have energies and wavelengths comparable to the elementary excitations and interatomic spacings in solids. This makes the neutron the ideal tool for probing the interactions dominant in the solid state. Additionally, the magnetic moment of the neutron can interact directly with the magnetic moment associated with unpaired electrons, so the neutron also serves as a probe of the magnetic nature of solids. The High Flux Beam Reactor (see discussion in Reactor Division) is one of the most intense sources of thermal neutrons in the world and allows for the study of a wide variety of problems. One example is given below.

The Excitations of Superfluid Helium Films

Among the many unusual features of superfluid helium, none is more remarkable than the fact that this liquid is the only one in which well-defined collective excitations—called phonons and rotons—can be observed. Most of what is known about these excitations comes from neutron scattering experiments. Indeed, so much has been learned over the years about the excitation spectrum of this quantum liquid that its bulk thermodynamic properties can be completely described in terms of the underlying microscopic dynamical response. But despite such meticulous investigation, the basic nature of the superfluid state is still not understood; the superfluid transition remains one of the great mysteries of many-body science.

Lately, the focus of attention in superfluid research has shifted from bulk studies to investigation of few-atomic-layer surface films. Much of the impetus for this new approach comes from the fact that such films are two- rather than three-dimensional and are easier to describe theoretically. Encouraging progress has been made in measuring the macroscopic thermodynamic properties of superfluid films and in relating them to theories of the two-dimensional superfluid transition. At Brookhaven, complementary microscopic measurements have recently been made with neutrons to characterize the collective excitations of one type of superfluid film of interest; namely, the film formed when helium is adsorbed on graphite. Major emphasis in this program has been on determining what happens to rotons, i.e., excitations with momenta in the range between 1.8 and 2.2 $Å^{-1}$, as the superfluid film is progressively reduced in thickness to monolayer dimensions. It was found that bulk-like rotons, although increasingly broadened by boundary scattering, can be identified in the films down to a total thickness of roughly three atomic layers, two of these being solid layers and one liquid. Also observed was a well-defined, lower-energy excitation (not seen in bulk superfluid) which is believed to be a mode propagating in the high density liquid at the boundary between the liquid and solid layers of the film. This mode, by virtue of the fact that it appears to be confined to the boundary layer, is thought to be the two-dimensional counterpart of the three-dimensional roton.

X-RAY SCATTERING STUDIES

Solid state is also involved in X-ray scattering and absorption studies. This effort will grow as NSLS becomes available.

EXAFS Studies of Dilute Alloys

There is structure in the photoabsorption coefficient of an atom in a condensed medium, at photon energies above threshold for photoejection of a core electron. These modulations arise due to the scattering by the surrounding medium of the ejected electron, back to the atom from which it originated. The existence of such extended x-ray absorption fine structure (EXAFS) had been known since the early 1930's, but it has only been recently, with the availability of the very intense broad spectra of photons from storage rings, that it has become practicable to extract near-neighbor distances and numbers and species of near-neighboring atoms about the absorbing atom. EXAFS is a powerful tool in that it provides atomic specificity, the core electron binding energies are different for different elements, and EXAFS can, in principle, probe the local structure about a very dilute species in a host matrix. Further, the technique does not require crystalline samples.

The present study of the internal oxidation of dilute (75 ppm) Fe in Cu alloys employs fluorescence detection with a crystal analyzer developed at Brookhaven as opposed to the standard transmission measurements. In transmission only the variation of the total absorption cross section is measured. The contribution from the dilute species may be as small as 1 part in 10^4 and if one is looking for variations in that fraction of the order of 1 to 10% then the measurement becomes impossible. However, the filling of the core hole created in the dilute species produces a photon of characteristic energy, and, because the fluorescence yield is a smooth function of the excitation energy, detection of these fluorescent photons is a measure of the absorption coefficient of the dilute atom. In order to push the limit of dilution detectable, a crystal analyzer, illustrated in Fig. 1, has been employed in the present study to distinguish the fluorescent radiation from the background of scattered incident

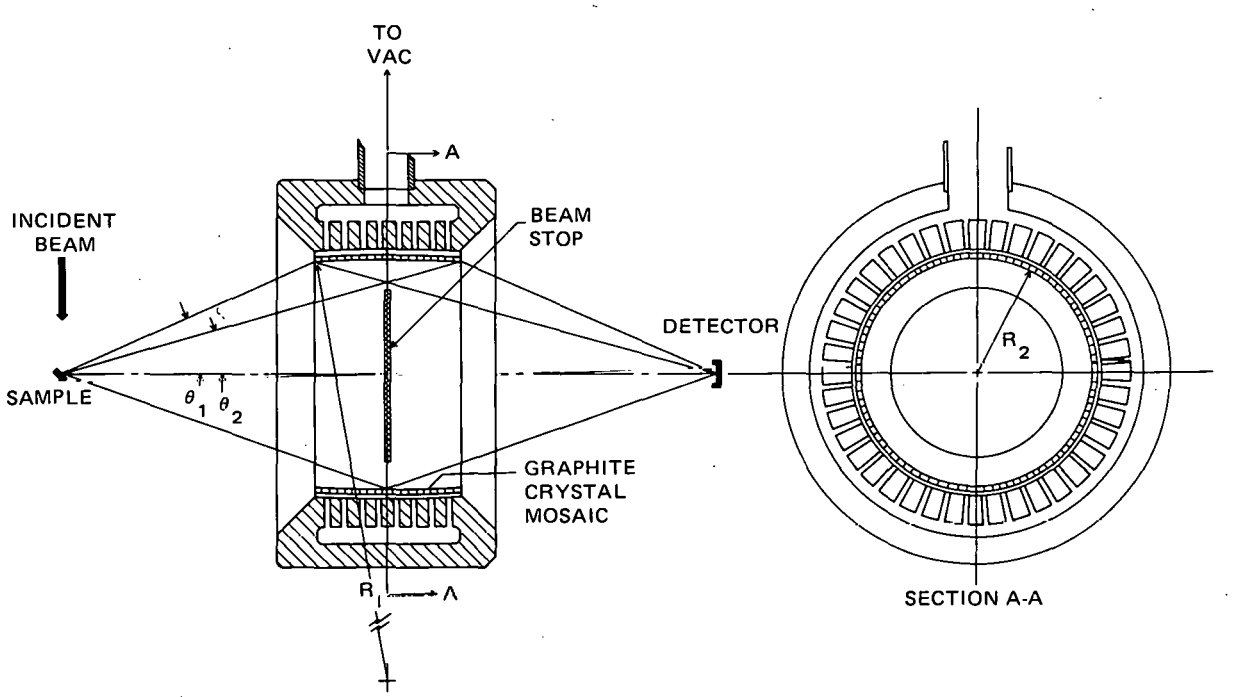

Figure 1. A large-solid-angle crystal analyzer for filtering x-ray fluorescence from specimens in extended x-ray absorption fine structure (EXAFS) measurements. The radius of curvature, R_1, of the graphite crystal mosiac determines the x-ray wavelengths accepted. The mosaic is mounted on a flexible rubber backing and may be transferred to a base plate of different radius in order to filter a different wave length range.

radiation. This detector collects a significant solid angle of the emitted fluorescent radiation. With it a study, hitherto impossible, was carried out and the results are outlined below.

The FeCu system exhibits the interesting feature upon oxidation that the residual resistivity ratio typically decreases by three orders of magnitude. Previous studies of these alloy systems have shown that the iron impurities cluster upon oxidation, but were unable to determine the local structure of the iron atoms in these clusters. EXAFS spectra were collected on oxidized and reduced alloys of 75 parts per million of Fe in Cu. In the reduced alloy the iron atoms were found isolated at substitutional sites in the copper matrix with a near-neighbor distance indistinguishable from the Cu-Cu distance in copper metal. The oxidized sample gave a dramatically different spectrum which showed Fe coordinated by Cu and oxygen as well as other Fe atoms. The distances measured were not identical to the predicted $CuFe_2O_4$ precipitates, however the structural parameters for $CuFe_2O_4$ correspond to equilibrium conditions obviously not present in the internal growth of these clusters. This study indicates the feasibility of looking at very dilute systems and gives EXAFS much promise as a tool to investigate local structures at very low concentrations.

SOLID STATE THEORY

The solid state theory group interacts strongly with the experimental sectors. Of concern are the bulk and surface properties of solids, defects, and critical phenomena.

Monte-Carlo Renormalization Theory of Critical Phenomena

At a critical point, a physical system undergoes a continuous transition to a state exhibiting some kind of long-ranged order. One of the more familiar examples is the establishment of the macroscopic magnetization in a ferromagnet. As the critical temperature is approached, the impending transition is signalled by the existence of fluctuations in whichever growing regions of the system exhibit the order that eventually will be established. The fluctuations may be explored by neutron or x-ray scattering, and they have been the subject of extensive theoretical and experimental study — particularly, in the past fifteen years or so.

One of the more useful theoretical approaches is to break the system into blocks, each containing several spins or other entities. The blocks are then regarded as elementary units whose state is characterized by means of a small number of variables, that are used to express the "renormalized" mechanics of the system. By repeating this procedure, it is possible to study how physical properties change from one length scale to another, and thus to work out the behavior of the system near to a critical point. However, it frequently happens that the accuracy of the method is limited by the absence of small parameters which may be used as the basis of a systematic approximation scheme.

To overcome this difficulty, the calculations were carried out by the Monte Carlo method, in which block properties were evaluated by means of numerical experiments carried out on a computer. This turned the whole approach into a controlled procedure, in which approximations could be improved and errors assessed in a systematic way. So far it has been more widely applied to two-dimensional systems, many of which are accessible to experiment, and it has proved successful for some previously unsolved problems. Block renormalization has been fashioned into a reliable method of computing critical properties by the application of a technique which, in its own way, has already contributed so much to our understanding of the physics of condensed matter.

DEFECTS AND DISORDER IN SOLIDS

Atomic defects and lattice disorder play a major role in determining the macroscopic properties of real solids, that is, imperfect solids. Aside from its basic scientific interest the Brookhaven program has practical significance, as knowledge of the factors which determine the properties of solids is a prerequisite for the creation of new materials tailored to the needs of a nation which depends heavily upon sophisticated energy technologies. The examples to follow indicate two of the methods used to address these problems with the tools of basic research, and illustrate the kinds of information obtained from their application.

Slow Positron Beam Research

Studies of positron annihilation in condensed matter have taken a new direction with the advent of slow-positron beams at Brookhaven. In the beam devices, positrons from a ^{58}Co source are implanted in a sulfur-coated, high-purity copper converter. About one in every ten thousand positrons is re-emitted, and each has an energy of a few electron volts. These low-energy positrons are extracted from the vicinity of the converter and transported to a target by magnetic or electrostatic guide fields. All of this is accomplished under ultrahigh vacuum conditions so that the positrons do not annihilate with electrons along their path to the target, and the target surface remains unchanged during subsequent measurements. A ten-stage electrostatic accelerator in front of the target is used to establish the incident energy of the implanted positrons.

Measurements of the gamma-ray spectrum of the positrons annihilating in the target, and at its surface, are quantitatively analyzed on the basis of a one-dimensional diffusion model. This model supposes that the implanted positrons have several pathways to annihilation. They may annihilate while free in the target, after becoming trapped at a lattice defect, or after returning to the surface. In the last instance, they may become trapped in and then thermally detrapped from surface traps. Often, upon detrapping they form positronium (Ps), the hydrogen-like bound state of an electron and positron pair. The fraction of Ps atoms formed depends upon the target temperature, the initial implantation energy and critically upon the state of the surface.

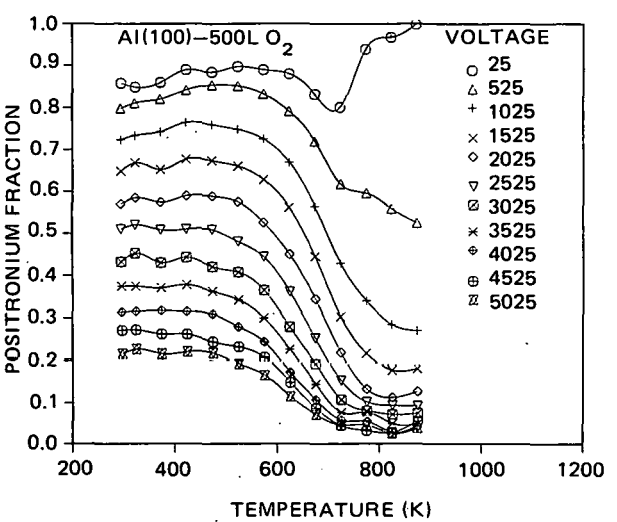

Figure 2. The fraction of positrons converted to positronium versus sample temperature at various incident positron energies for Al (100) after exposure to 500 langmuir of oxygen. The solid lines shown in the figure are produced by a spline fit to the data. The sample remained at each temperature for approximately 15 minutes. After the high temperature run the positronium fraction was measured with decreasing temperature and no minimum appeared for the lower energy positrons in the temperature region between 600-800 K.

Recent measurements on clean Al targets and on oxide-coated Al targets have clearly established the sensitivity of slow positrons to surface conditions. As oxygen is adsorbed on the Al, the initial Ps fraction increases and then decreases. Figure 2 illustrates the behavior of the Ps fraction at an Al surface which has been exposed to 500 langmuir of oxygen. The amorphous-to-crystalline surface transition of Al_xO_y on Al is signalled between 650 and 800 K by the change in the Ps fraction. The abrupt reversal of the Ps fraction is thought to be caused by the removal of trapping centers in the metal-oxide overlayer during the phase transition. Interpretation of data for the Ps fraction on clean surfaces in terms of a diffusion and trapping model yields vacancy formation energies, surface electronic properties, and fundamental information about the interaction of positrons with condensed matter. This technique thus provides a new experimental tool for the study of interfaces, thin films, and vacancy-type defects associated with them.

Radiation Effects in Synthetic and Natural Rock Salt

Evaluation of long-term storage in nuclear waste repositories depends critically upon an understanding of radiation effects in the surrounding host rock. In order to identify the basic phenomena occurring when rock salt is exposed to ionizing radiation, a research program has been established using energetic electrons or ^{60}Co gamma rays.

Synthetic and natural NaCl are investigated optically during and after exposure to radiation. Natural conditions are simulated by elevating

the sample temperature and, in the case of the synthetic NaCl, by straining the samples prior to irradiation. The natural rock salt samples are found to be strained when they are received from geological sites. Dislocations produced by this strain serve as nucleation sites for Na colloids, that is, small clusters of Na atoms distributed randomly throughout the sample, and profoundly reduce the induction period preceding growth of detectable colloids. These phenomena are seen in Fig. 3 which shows the growth of the colloid absorption band in synthetic NaCl versus exposure for different applied strains. Comparison of corresponding data in natural salt and highly strained synthetic salt reveals the similarity between them, and thereby the dependence of radiation-induced colloid formation on dislocation density. It is apparent that the formation of colloidal sodium in the natural rock salt of radioactive waste repositories will modify the physical and chemical properties of the salt. This will have an important effect on the interactions between the stored waste and the surrounding host rock.

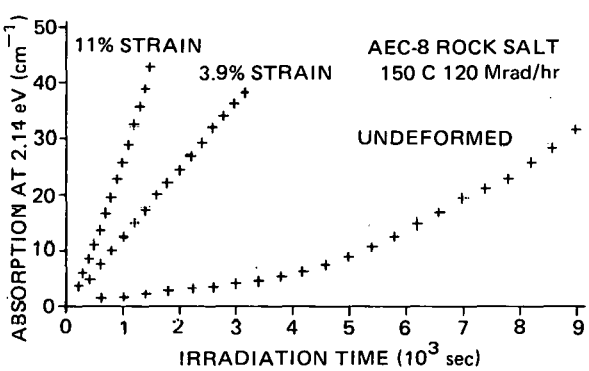

Figure 3. Growth of optical absorption in natural rock salt during electron bombardment at 150°C. Data are given for three single crystal samples (~ 10 × 10 × 0.5 mm) deformed along the <100> axis by the amounts indicated, prior to irradiation. The optical absorption at 2.14 eV is attributed largely to colloidal sodium particles.

SURFACE PHYSICS

In recent years the surface physics program has grown in anticipation of the unique capabilities which will be available at the National Synchrotron Light Source (NSLS). Besides work directly related to the facilities at NSLS a broad program of the study of surface problems is underway involving studies of reactions on surfaces, the interaction of slow positrons with surfaces (as has been described above), the interaction of ions with surfaces, and studies of electronic and structural properties of surfaces with photoemission spectroscopy.

Hydrogen Absorption in Metal Crystals

Hydrogen in metals is of interest because its presence tends to embrittle metals and because of the possibilities for hydrogen storage — more hydrogen can be stored in a metal host than in an empty tank of equivalent volume. Hydrogen adsorption is, of course, important to catalytic action. Rarely, however, have the surface and bulk properties been related in any way. It was recognized that the rate of solution of hydrogen in metals was influenced by the state of the surface but the mechanism was not understood. Recently the techniques of surface science, which include ultrahigh vacuum, low energy electron diffraction (LEED), and ultraviolet photoemission, have been applied to this problem. The experiments were done jointly in the physics and materials science departments. First it was learned that atomically clean surfaces of niobium and tantalum have a very low "sticking coefficient" for hydrogen. That is, molecules in the gas phase which strike the surface are ordinarily reflected rather than transmitted through the surface region into the bulk. However, coating the surface with 1 to 3 layers of palladium results in a sticking coefficient near unity — every molecule which strikes penetrates into the interior. A model has been developed which attributes this behavior to the difference in bond energy of a hydrogen atom at the surface compared to the bulk. The Nb surface bond is stronger, so the surface saturates before the bulk and blocks further entrance of hydrogen. The palladium surface bond is weaker by about 0.15 eV/H atom which is enough to keep the surface free to accept more hydrogen until the bulk is filled. LEED studies have shown that the palladium is adsorbed in a geometrical structure which is the same as the underlying niobium crystal — it is a commensurate overlayer. When the palladium coverage exceeds 1 layer a new structure is formed which is incommensurate and has the same spacing as the (111) plane of the Pd crystal. It is the incommensurate structure which allows

the enhanced hydrogen uptake. The electronic states of this system have been probed by angle-resolved photoemission. This type of spectroscopy will be greatly facilitated when the National Synchrotron Light Source is completed. The fact that synchrotron radiation is polarized means that dipole selection rules may be used to deduce the symmetries of the states involved and since the wavelength is variable, transitions may be selected which enhance the bulk or surface states as desired. Even without the light source it has been possible to clearly identify the palladium-induced states, to see that Pd states near the Fermi level are absent in the commensurate layer but appear when it goes incommensurate, and to monitor the effects of only a few layers of hydrogen on the bonding electrons of clean metal surfaces.

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The National Synchrotron Light Source

INTRODUCTION

Design and construction of the National Synchrotron Light Source started in FY 1978 with construction funding coming from the Department of Energy. The total project comprises a linear accelerator and booster synchrotron as an injection system for two electron storage rings operating at energies of 700 MeV vacuum ultraviolet (VUV) and 2.5 GeV (x-ray). At the time of writing, the building which houses the linear accelerator, the booster synchrotron and the two storage rings is about 50% complete (Fig. 1). Brookhaven will take over beneficial occupancy of the vacuum ultraviolet ring portion of the building next December and installation of the storage ring components will start at that time.

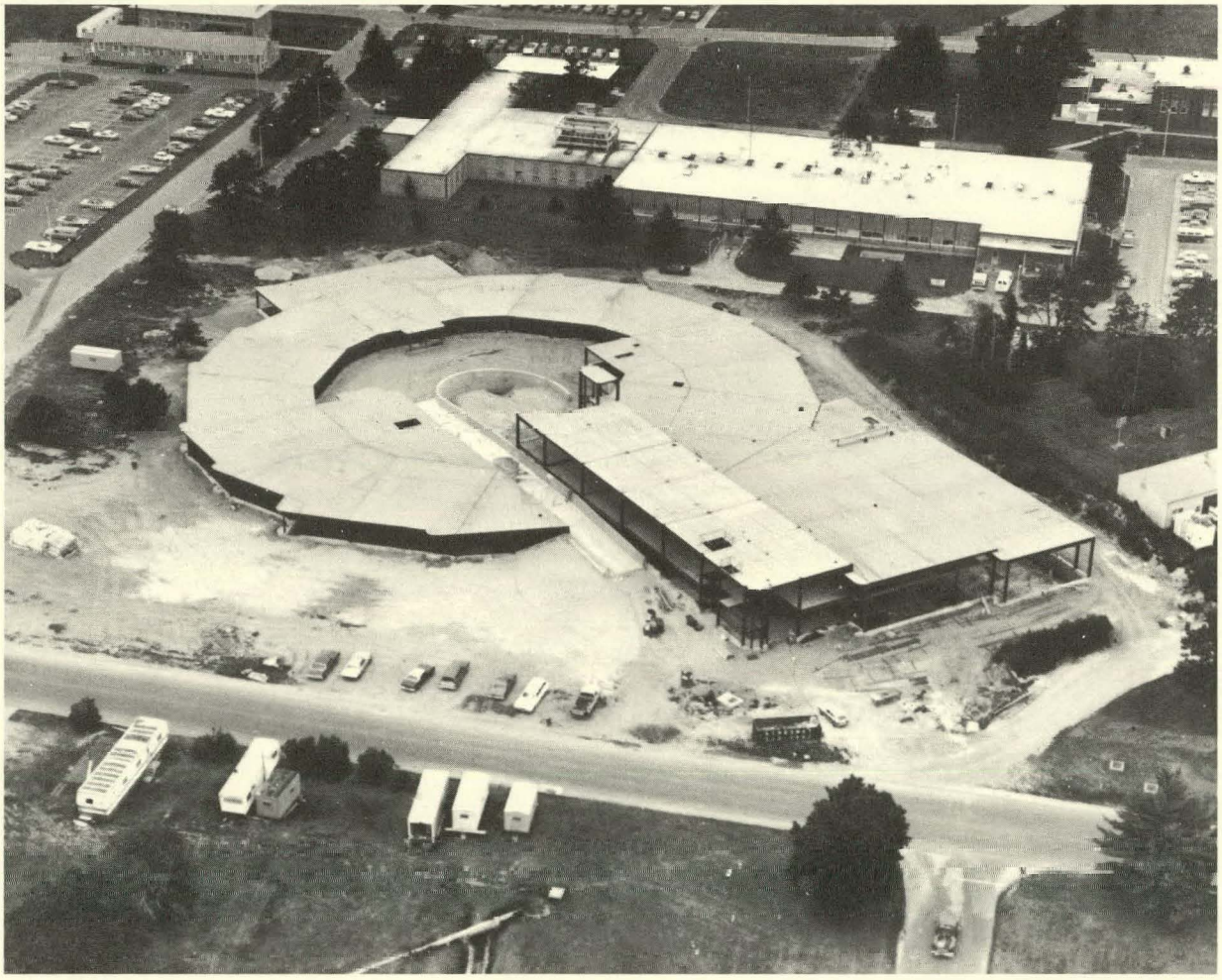

Figure 1. National Synchrotron Light Source building under construction.

MACHINE HARDWARE STATUS

The detail design of the storage rings and the injection system is almost complete and much of the actual hardware is either in house or on order. All of the magnetic elements are being assembled at BNL by project staff and contract technicians. Figure 2 shows the magnetic focusing elements for the VUV ring being placed on their support stands. The building which formerly housed the 80-inch bubble chamber is being used for magnet assembly and measurement as well as a test area for the dc power supplies for these magnets. In an adjacent area, assembly and testing of the components which make up the radiofrequency power systems is taking place. These units will provide the energy to the circulating beams of the two storage rings which, upon being bent in the magnetic dipoles, radiate the photons used by the experimental groups for their research purposes.

The electron linac injector for the booster synchrotron is made up from parts of machines from Cornell, Cambridge, and Amsterdam, Holland which have all been superseded by higher current machines. The various pieces have now been assembled in Building 925 at Brookhaven and a new diagnostic system for the accelerator is being designed. Frequent beam tests are being made as the older controls are replaced by a more modern microprocessor-based system.

The NSLS control system utilizes two Data General Eclipse 5250 computers which are connected to microprocessors throughout the facility through a network utilizing three Nova Computers. This system is already in use for both the magnetic measurement program and for operation of some of the linac components.

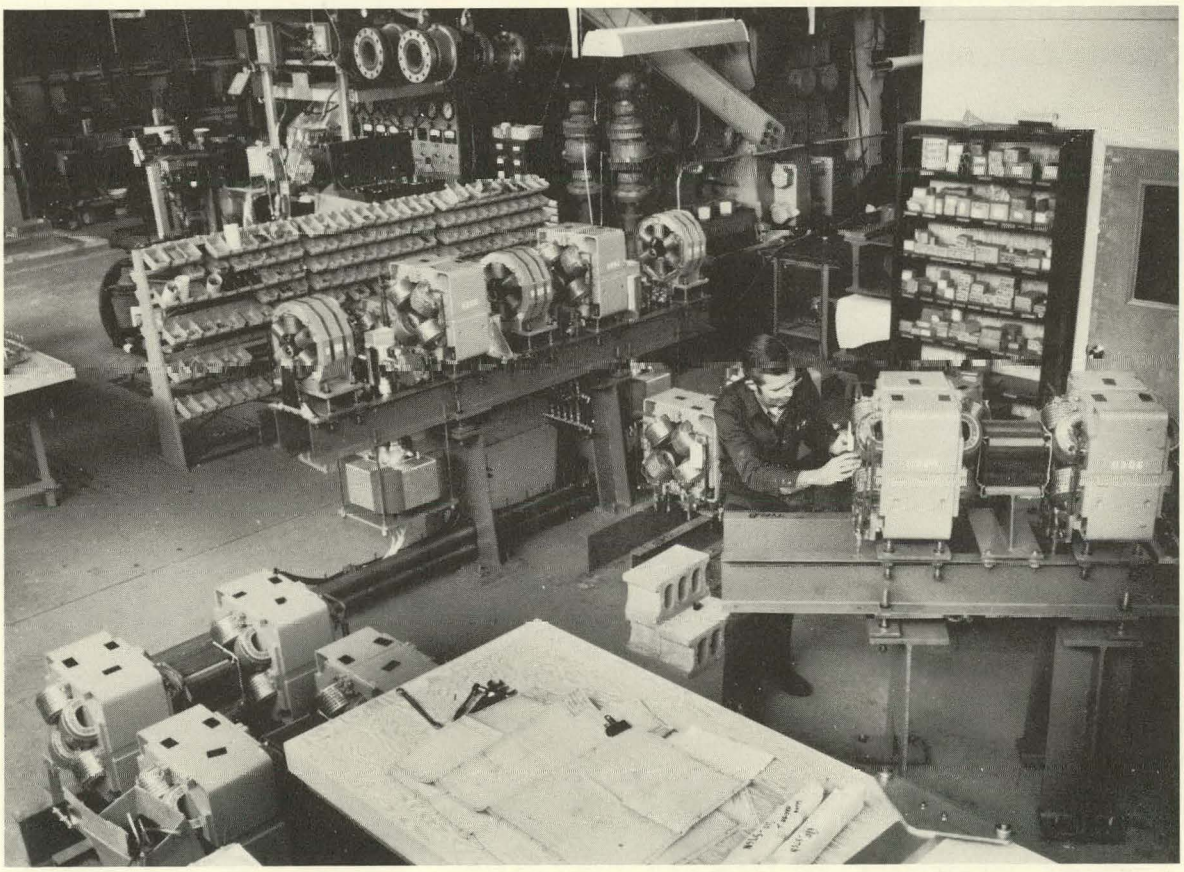

Figure 2. Magnetic focusing elements for the vacuum ultraviolet (VUV) ring being mounted on their supports.

In order to store the electron beams for long periods in the storage rings, it is necessary to achieve vacuum pressures in the 10^{-10} Torr range before the beam is injected, and 10^{-9} Torr operationally. The design of the vacuum chamber and pumping systems necessary to achieve this and the fabrication of the various components has been carried out in the basement of Building 535. In addition, a special cleaning facility for all vacuum components has been established in Building 197.

EXPERIMENTAL BEAM LINE DESIGN

While the design and fabrication of the machine components have been progressing, a pulsed light source on a test bed, monochromator, slit assembly, etc. has been developed for use in the vacuum ultraviolet ring experimental facility (see Fig. 3). For the x-ray experimental facility, monochromator and mirror designs are in progress, a rotating anode x-ray generator has been obtained, and a suitable test area is being prepared for the installation of this unit. This will be used for crystal testing and alignment, beam line optical measurements, and the checking out of apparatus to be used in the x-ray beam lines.

The project staff has been in close cooperation with outside participating research teams to set up the schedule and program of beam lines to be on line when the facility first operates in 1981. Some of the early experiments on the VUV ring will focus upon such areas as absorption, reflectivity and fluorescence spectroscopies, very high resolution gas spectroscopy, photochemistry, and biophysical spectroscopy. In the x-ray ring, investigations will include small angle scattering, x-ray absorption fine structure, and x-ray diffraction.

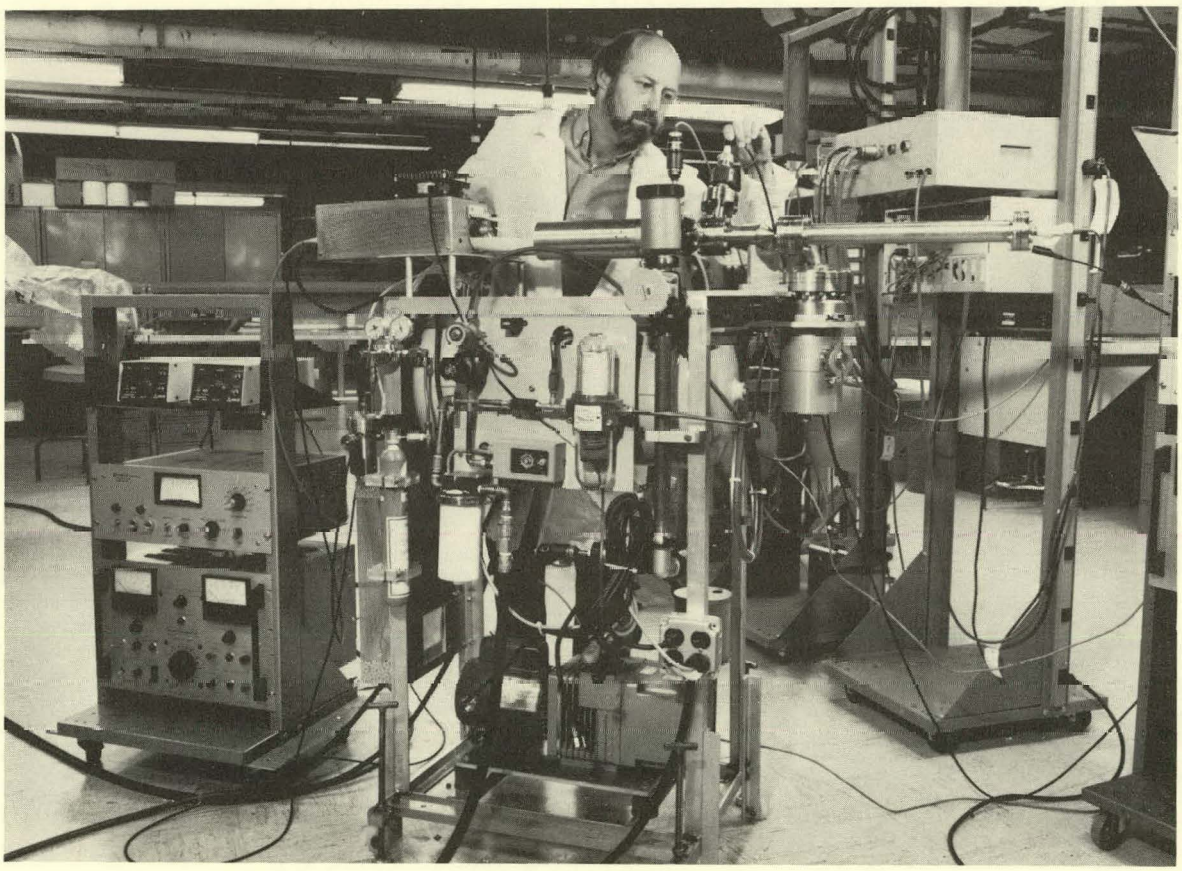

Figure 3. Pulsed light source for use in the VUV ring experimental facility.

NATIONAL SYNCHROTRON LIGHT SOURCE

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M. Blume, Deputy Project Head
J. Godel, Assistant Head, Construction Coordination
K. Batchelor, Assistant Head, Administration
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J. Hastings — X-ray Beam Lines
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G. Williams — VUV Beam Lines

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Chemistry Department

INTRODUCTION

Research interests in the Chemistry Department cover a wide spectrum of topics, ranging from the study of enzyme catalysts to the investigation of high-energy nuclear reactions. Although many of the research programs are similar to those carried out in universities and other research institutions, others require facilities unique to Brookhaven, such as the High Flux Beam Reactor or various particle accelerators. To this list will soon be added the National Synchrotron Light Source. A significant fraction of the work described below represents research carried out in collaboration with colleagues within the Chemistry Department and other BNL Departments, or with scientists from universities and industry.

STRUCTURAL CHEMISTRY

Neutron and x-ray diffraction are powerful tools for investigation of the three-dimensional structure of crystalline substances at atomic resolution. At BNL, intense beams of thermal neutrons from the High Flux Beam Reactor are being used in structural studies of interesting and novel materials, including transition-metal hydride coordination compounds, hydrogen-metal alloy systems, and ionic conductors. For example, the molecular structure of a tetrahedral metal complex with edge-bridging hydride ligands, $H_4Ru_4(CO)_8(P(OCH_3)_3)_4$, was recently determined in collaboration with scientists from Cambridge, England. This work involved the location of a total of 176 atoms in two independent molecules, representing the largest structure ever to be refined to convergence directly from neutron diffraction data. Neutron diffraction allows extremely accurate location of hydrogen and other light atoms in structures containing heavier elements, and as such is uniquely suited to the study of chemical bonding in metal hydrides. Information gained from such studies may be important in the design of metal-hydride systems for hydrogen storage applications.

Efforts are underway to prepare and characterize new metal-cluster compounds. Clusters are discrete molecules or ions containing three or more metal atoms, often arranged in a polyhedral fashion, and surrounded by a number of ligands such as CO or phosphines. Cluster structures may provide clues to the general principles underlying the interaction of small molecules with metal surfaces, and many clusters display catalytic activity. Recently, a pentanuclear rhodium carbonyl anion, $[Rh_5(CO)_{15}]^-$, has been isolated and its structure determined[1] in an x-ray study (Fig. 1). This species, which takes the form of a trigonal bipyramid, is a likely catalyst precursor in a process developed at Union Carbide for synthesis of ethylene glycol from CO and H_2 at high pressure with a homogeneous rhodium catalyst. A number of rhodium carbonyl clusters

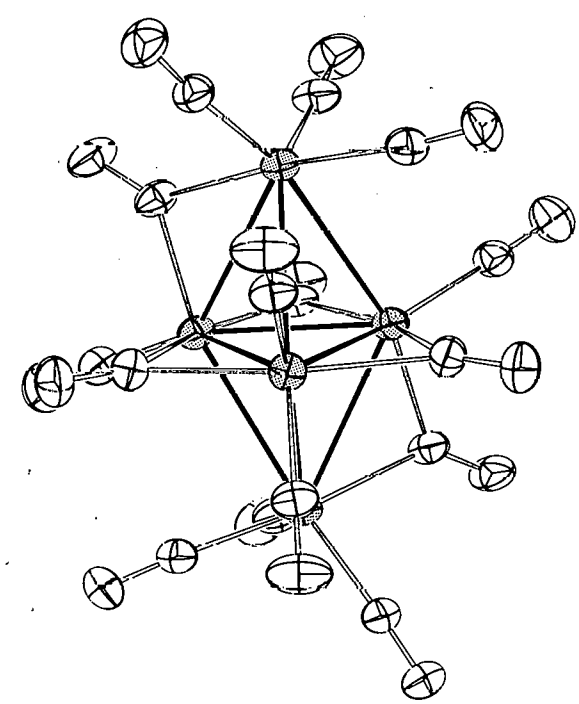


Figure 1. View of the $[Rh_5(CO)_{15}]^-$ anion with ellipsoids representing amplitudes of thermal vibration observed in an x-ray diffraction study at room temperature. Rhodium atoms are shaded.

appear to play a role in this reaction; the anionic pentanuclear species has definitely been found at temperatures somewhat below those used for the actual reaction.

The National Synchrotron Light Source, now under construction, will provide very intense x-rays over a wide spectral range. The unique properties of this source will make possible many exciting new experiments in structural chemistry, when beams become available in late 1981. For example, in combined x-ray and neutron diffraction studies of charge densities in solids, the extraordinary x-ray intensity may lead to a much greater accuracy than that attainable with conventional sources. Studies of perturbed samples, such as electronically-excited crystals, may also become possible.

NEUTRON DIFFRACTION

In certain antiferromagnetic compounds, as a result of crystal field effects or crystal geometry, sublattices of positive and negative spins respond differently to an applied magnetic field. This unequal response is physically equivalent to having different fields acting on each of the sublattices. The applied field can therefore be replaced by a uniform field acting equally on the two sublattices and an alternating or "staggered" field which adds to or subtracts from the field common to both. This staggered field induces an additional staggered, or antiferromagnetic, moment and was first detected in work in this Department on the magnetic phase diagram of dysprosium aluminum garnet (DAG). Although the effect is small in DAG, it was predicted to be considerably larger in the isomorphic compound dysprosium gallium garnet (DGG) because of the nature of the g-tensor. Calculations and measurements of the effect at various fields and temperatures were carried out in collaboration with Yale University and the BNL Physics Department. As expected, application of a field produced strong Bragg antiferromagnetic reflections in the *paramagnetic* region, where no long-range order exists in zero field. The intensities at low fields (0-10,000 Oe) agreed quantitatively with calculations to within the known uncertainties in the g-factors. At higher fields (10,000-40,000 Oe), satisfactory agreement was obtained by including the anisotropy in the Van Vleck temperature-independent susceptibility.

THEORETICAL CHEMISTRY

A major effort in theoretical chemistry is directed at a detailed analysis of the kinetics of electron exchange between solvated transition metal complexes in solution. The research identifies critical aspects of the relevant electronic structure requiring sophisticated, large-scale, quantum mechanical calculations for which the Laboratory computer facilities are ideally suited. The results of these calculations are then combined with other data to provide full characterization of the reacting system (schematically represented in Fig. 2, for the important prototype case of interacting aquo-Fe ions) in terms of solvent reorganization, metal-to-ligand charge transfer, and metal-metal and ligand-ligand overlap. The latter factors have been successfully used in rationalizing trends in the rate constants for various Fe and Ru complexes, and the detailed quantum chemical results have also been employed as a reference point in calibrating simpler classical and semi-classical models. Figure 2 illustrates a reaction-favorable encounter geometry (transition state), which optimizes the overlap of the relevant atomic orbitals on each reactant. The weak overlap contributes strongly to the observed slowness of the reaction in aqueous solution.

A useful contrast between the solvation effects of weakly polar solvents and strongly polar solvents (including those capable of hydrogen-bonding) is provided by the specific intermolecular effects exerted by the solvent toward a specific solute. These effects must be corrected for a background of non-specific medium effects that do not depend on molecular details of the solvent or solute. This background function can be derived by slight modification of a general continuum theory proposed by Onsager almost half a century ago. The modifications remove a major physical inconsistency that results if a discontinuous change in the permittivity at the solute-solvent boundary is assumed. The revised theory leads to improved correlations among individual molecular and condensed phase properties such as dipole moments, polarizabilities, and dielectric constants. These results provide support for the validity of the revised the-

ory and indicate its promise for future applications.[2]

During the past year, a dedicated minicomputer system for large-scale calculations of the energetics and dynamics of molecular collision phenomena was put into full-time operation. These calculations generate exact solutions of the classical equations of motion (i.e., trajectories) for chemically reactive atom-molecule collisions, using potential energy functions evaluated by numerical solution of an eigenvalue problem describing the electronic energy of the system. The primary requirements for fast double-precision (64-bit) floating point arithmetic and modest amounts of fast memory make these calculations well-suited to a minicomputer. Owing to the Monte Carlo method employed for averaging the dynamical results over all possible collisions (i.e., random selection of initial conditions for each trajectory), large numbers of trajectories must be computed to obtain a statistically valid sample of collision events. The use of a high-performance minicomputer has provided a convenient and cost-effective manner of supplying the "computing power" that such calculations require.

The particular minicomputer system employed in this work, a PDP 11/45 CPU with floating point processor and memory management, 128K 16-bit words of fast MOS memory, a 1K-word cache memory, and a 300 Mbyte disc drive, can stream double-precision floating point operations at about one-eighteenth the single-precision (60-bit) speed of a CDC 7600 computer.

INORGANIC SOLUTION KINETICS AND PHOTOCHEMISTRY

Although electron-transfer reactions have been most extensively studied as *intermolecular* processes[3] [Eq. (1)],

$$A^- + B \rightleftharpoons A + B^-, \qquad (1)$$

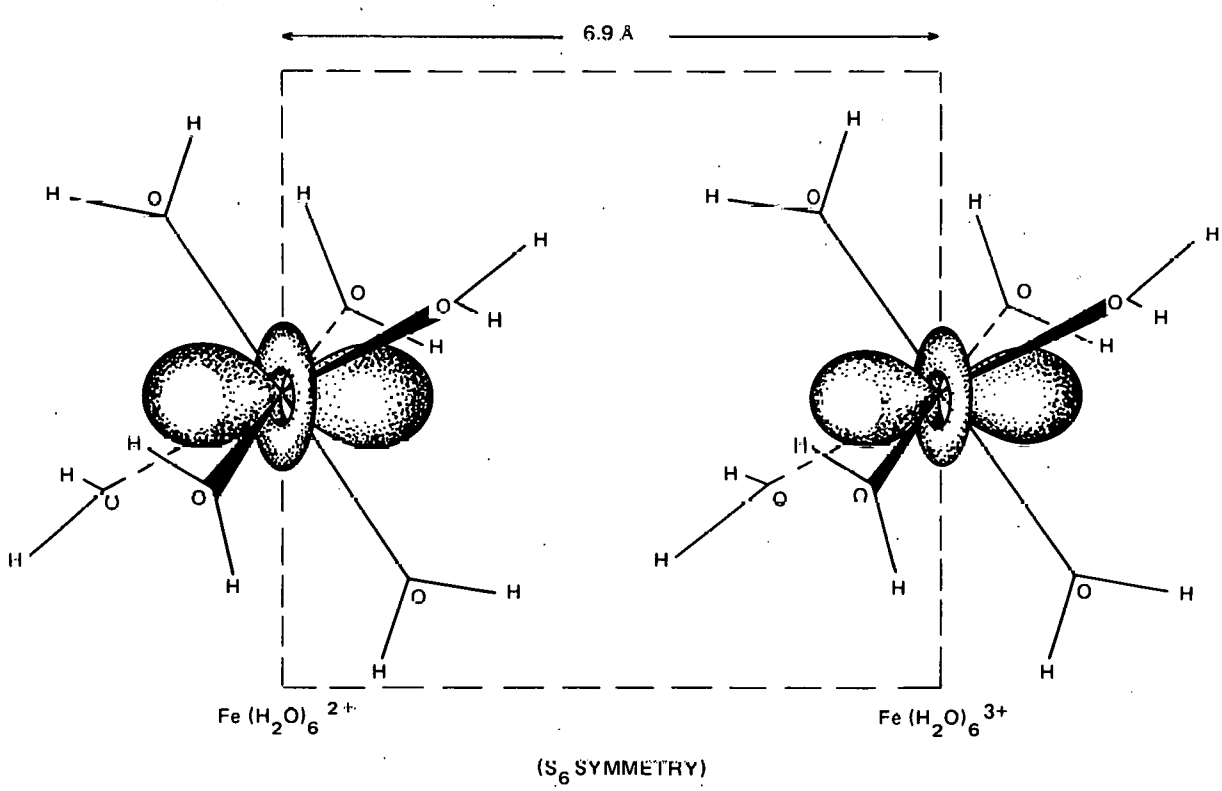


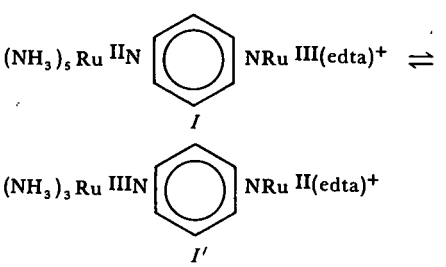
Figure 2. Schematic representation of the interaction between hydrated ferrous and ferric ions. The two atomic orbitals explicitly displayed are those directly involved in the electron hopping.

the comparison of observed rates with those calculated from theory is most readily carried out for *intramolecular* reactions [Eq. (2)],

$$A^- \sim B \rightleftharpoons A \sim B^-, \qquad (2)$$

where A and B represent reducing and oxidizing sites in the same molecule. This is because, for *intramolecular* processes, observed rates need not be corrected for the fact that A^- and B must be brought into contact to undergo reaction. In some *intramolecular* electron transfer systems the spectroscopic properties (in addition to the dynamic properties) of the molecule permit an additional test of theory. Binuclear mixed-valence ions[4] in which there is a moderate interaction (H_{12}) between the two metal centers exhibit new absorption bands at an energy (E_{op}) related theoretically to the thermal barrier (E_{th}) for electron transfer between the metal centers as indicated in Fig. 3. The magnitudes of E_{op} and E_{th} are related to the changes in solvation which accompany the electron-transfer reaction.

The technique of picosecond absorption spectrophotometry has been used[5] to measure the intramolecular electron-transfer rate I′ → I [Eq. (3)]. In this technique,



(3)

the binuclear ion is irradiated with a laser pulse of 10^{-11} sec (10 psec) duration. When the ion *I* absorbs a photon, an electron is transferred from the ruthenium (II) end to the ruthenium (III) end of the molecule (*I*→ *I*′). The return of the electron to its initial position after the laser pulse is followed by optical absorption measurements. The rate constant measured for this process is 10^{10} sec^{-1}, while that calculated from theory and the absorption spectrum of *I* is 50 times larger. This result, together with the photophysical behavior of the system, shows that the relatively long time required for solvent repolarization may be rate limiting in some electron transfer reactions.

PICOSECOND SPECTROSCOPIC STUDIES OF ARTIFICIAL PHOTOSYNTHESIS

The transformation of sunlight into chemical energy in photosynthesis proceeds through the rapid production of oxidants and reductants.

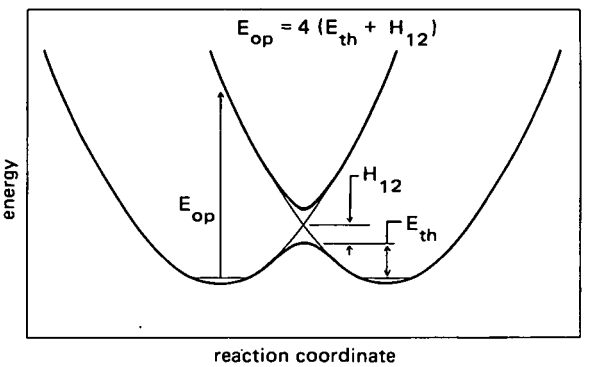


Figure 3. Plot of the potential energy of $A^- \sim B$ (curve on left) and $A \sim B^-$ (curve on right) along the reaction coordinate. The vertical distance E_{op} reflects the energy required to transfer an electron from A to B when both have the equilibrium nuclear configuration of $A \sim B$. The thermal electron transfer has a lower barrier E_{th}, when A, B, and surrounding solvent molecules have rearranged to a configuration intermediate between that of $A^- \sim B$ and $A \sim B^-$. In one simple limiting case, $E_{op} = 4(E_{th} + H_{12})$, where H_{12} is the interaction energy.

This process has been most clearly described for reaction-center protein complexes isolated from photosynthetic bacteria. Here the initial light-driven chemical process consists of the oxidation of a bacteriochlorophyll (BChl) dimer and the reduction of bacteriopheophytin (BPheo), a dimetallated BChl. The reaction

$$(BChl)_2\ BPheo \xrightarrow[<10\ psec]{h\nu} (BChl)_2^{+}\ BPheo^{-} \qquad (1)$$

captures about 70% of the 1.4 eV of energy in the incident photon and essentially all of the absorbed photons yield chemical products.

One research goal of this laboratory is to design and construct multi-component molecular complexes that can produce high yields of energy efficient photoproducts. The first step toward this goal is to determine the molecular

requirements for producing efficient reactions in which an excited singlet (S_1) undergoes charge transfer (CT).[5-7] Numerous studies have shown that one cannot simply dump an excess of electron acceptor into solution with an excited electron donor and get significant yields of electron transfer photoproducts. Apparently, several factors control $S_1 \rightarrow CT$ reactions, including the rigidity of the electron donor and acceptor molecules, their relative orientation, their distance of separation, the energy of their excited states, and their redox properties.

The first type of molecular complex studied is shown in Fig. 4. It is a cofacial diporphyrin with a separation of ~ 4 Å between the two OEP (octaethylporphin) rings.[8] Electrochemical measurements showed that it would be easier to form a CT product in a diporphyrin with one magnesium atom ($Mg\text{-}H_2$) than in diporphyrins with two or zero magnesium atoms (Mg-Mg, and H_2-H_2). They also showed CH_2Cl_2 (methylene chloride) to be a better solvent than THF (tetrahydrofuran) because the electron donor is more readily oxidized.

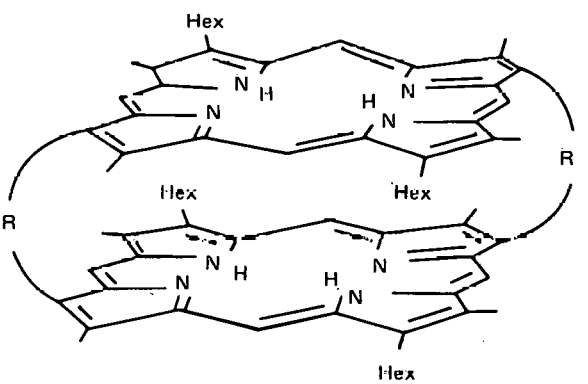


Figure 4. Structural drawing of a diporphyrin comprised of two free base units, H_2–H_2. The covalent bridges are

$$R = -CH_2-CO-N(n\text{-butyl})-CH_2-CH_2-.$$

Picosecond spectroscopic experiments in THF showed all of the diporphyrins (containing two, one, and zero magnesium atoms) to have similar excited state absorption spectra and lifetimes > 3 nsec. Mg-OEP and H_2-OEP have singlet lifetimes of about 15 nsec. However, in CH_2Cl_2 the diporphyrin with a single magnesium atom, $Mg\text{-}H_2$, had a distinctly different absorption spectrum, twice as intense and peaked in the 660 nm region (Fig. 5). This is exactly where one would expect the photoproducts, Mg $OEP^{+\cdot}$ and H_2 $OEP^{-\cdot}$, to absorb. Equation (2) summarizes this result:

$$Mg\text{-}H_2 \xrightarrow[<6\text{psec}]{\text{light}} Mg^{+\cdot}\text{-}H_2^{-\cdot} \qquad (2)$$

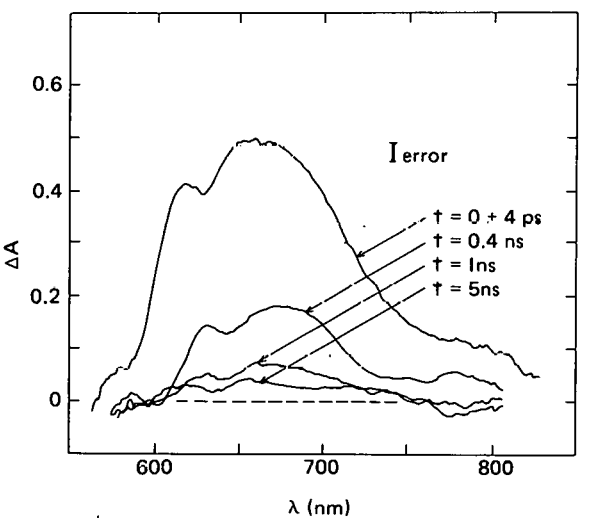


Figure 5. Transient absorption spectra for 5.6 × $10^{-4}M$ $Mg\text{-}H_2$ in CH_2Cl_2 after excitation at 527 nm with 6 nsec pulses. Samples were vigorously outgassed and sealed in 2 mm pathlength cells. The transient absorption decays with first-order kinetics with ΔA(t=5nsec) as the asymptote. The lifetime of this state is 380 ± 40 psec.

The back reaction to form two neutral porphyrins took place in 400 psec.

$$Mg^{+\cdot}\text{-}H_2^{-\cdot} \xrightarrow[400\ \text{psec}]{\text{dark}} Mg\text{-}H_2 \qquad (3)$$

The comparable back reaction in photosynthetic bacteria [the reverse of reaction (1)] takes 15 nsec. Therefore, although reaction (2) is more energy efficient (storing 92% of the incident photon energy) than reaction (1), its photoproducts decay 38 times more rapidly. To occur with greater than 90% efficiency, a second electron transfer will have to occur in less than 40 psec — a severe constraint. Apparently, a solar

energy conversion system with several electron transfer steps will have to trade energy storage efficiency at each step for an increase in the lifetime of the photoproducts. In other words, the best solar energy system cannot be built merely by storing the maximal amount of energy in each step.

To explore further the molecular properties governing electron transfer, the excited state behavior of linked two- and three-component pyrochlorphyllide *a* and pyropheophorbide *a* complexes is currently being studied. In no case is there evidence for a process like reactions (1) and (2) taking place in a few picoseconds. However, preliminary analysis suggests that the redox properties of these complexes can be chosen to produce a system that undergoes a $S_1 \rightarrow CT$ reaction with a lifetime of 110 psec. This photoreaction succeeds in storing 85% of the incident photon energy and yields photoproducts with a lifetime of 3000 psec.

The above studies and others currently in progress give hope that the initial electron transfer step will soon be understood. Once this is accomplished, work will begin on the problem of controlling electron flow through a series of secondary electron acceptors.

THE PROTON PUMP IN PURPLE BACTERIA

Certain bacteria living in highly saline water capture the energy of sunlight, convert it to chemical energy, and store it in the form of adenosine triphosphate (ATP). The driving force for the manufacture of ATP is provided by the higher acidity outside the cell compared to that inside. The difference in acidity develops when sunlight is absorbed by bacteriorhodopsin, a pigment in the cell, and this interaction causes protons to be pumped out of the cell. Bacteriorhodopsin is similar to the light detector in the eye, both being composed of a protein and a small molecule, retinal, which is the light collector. Other researchers have suggested that the protons translocated during the pumping cycle are at some time chemically bonded to the retinal. Experiments in which the pigment was disassembled and then reassembled in D_2O and subsequently activated by light show that these mechanisms are not possible.[9] Translocation of protons along hydroxylic side groups of the protein appears more probable.

IONIZATION AND ELECTRONS IN LIQUIDS

The chemical properties of electrons in liquids are important to an understanding of radiation and ionization effects. In liquids, the energetics of ionization processes differ from those in the gas phase in two ways: polarization of the liquid medium (a coulombic interaction) stabilizes ionic species, and the energy of the electron in the conduction band is different from its energy in vacuum. The threshold for ionization of neutral molecules in the liquid is expected to be lower than in the gas (a spectral red-shift). On the other hand, for ionization of anions (negatively charged species), the threshold would be higher than in the gas (blue-shift). A laser conductivity technique has been developed which is used with a Van de Graaff X-ray generator to determine ionization thresholds of anions in solution and their photodetachment (action) spectra in the visible region. With this technique it was found that the threshold of the reaction

$$0_2^- + h\nu \rightarrow 0_2 + e^-,$$

is shifted from the infrared region in the gas phase to the visible region in non-polar solvents, a blue shift of about 2 eV. Studies of this type have not only demonstrated a new spectroscopic technique for determining hitherto unknown spectra, but also provide quantitative information about the effect of solvent on ionization processes.

HIGH MOLECULAR WEIGHT MASS SPECTROMETRY

The mass spectrometer has been accepted as one of the most useful and sensitive analytical instruments in modern chemistry, with the added capability of providing structural information. A large and important class of compounds has been beyond the range of conventional mass analytical techniques because of the high molecular weights of these compounds. The detection, mass analysis, and generation of high molecular weight ions has been the subject of recent investigations in the BNL Chemistry Department. The problem of heavy ion detection has been attacked using a 400 kV post-acceleration terminal and a secondary electron detector system, per-

mitting very sensitive measurement of ions with mass/charge ratios in excess of 10^5 amu. A quadrupole mass analyzer equipped with a special low frequency power supply provides mass analysis up to mass/charge ratios of approximately 150,000. Most of the very recent studies have been devoted to ion source techniques designed to exploit the analysis and detection capabilities that are now available. An aerosol-type ion source that has been developed and tested generates cluster ions consisting of as many as 5000 water molecules. Both positive and negative ions have been extracted from this ion source. The ions generated have been used to investigate the energy transfer in the impact of ions on solid surfaces, using secondary electron yields as a measure of the amount of ion energy converted to electronic excitation on impact. These studies have been fruitful in showing a very small extent of energy conversion from translational ion energy to electronic excitation in the very hot zone of the solid produced by ion impact. The potential of the high molecular weight mass spectrometer facility that has been constructed is far from realized, since it has application in a variety of scientific disciplines. The major current interest and effort is focused on the further development of ion-source techniques, with particular attention to the generation of high molecular weight cluster ions that are involved in energy transfer studies and are important for an understanding of nucleation processes in the environment.

NUCLEAR CHEMISTRY

Investigation of the reactions between energetic projectiles and complex nuclei is a continuing program in the Chemistry Department. The basic goal of this work is an understanding of the mechanisms responsible for the complex mixture of products observed. A second component of the nuclear chemistry program is nuclear spectroscopy, with emphasis on searches for and characterization of new isotopes far from the line of beta stability.

Nuclear Reactions

Many aspects of the fragmentation of complex nuclei by energetic projectiles can be understood in terms of a two-step model involving an initial fast abrasion interaction followed by a slow ablation step. It has been observed that the final distribution of projects after the ablation step is remarkably independent of projectile type and energy (for bombarding particles as diverse as π mesons and ^{40}Ar ions). This behavior is consistent with the theory of limiting fragmentation, which predicts that target fragmen-

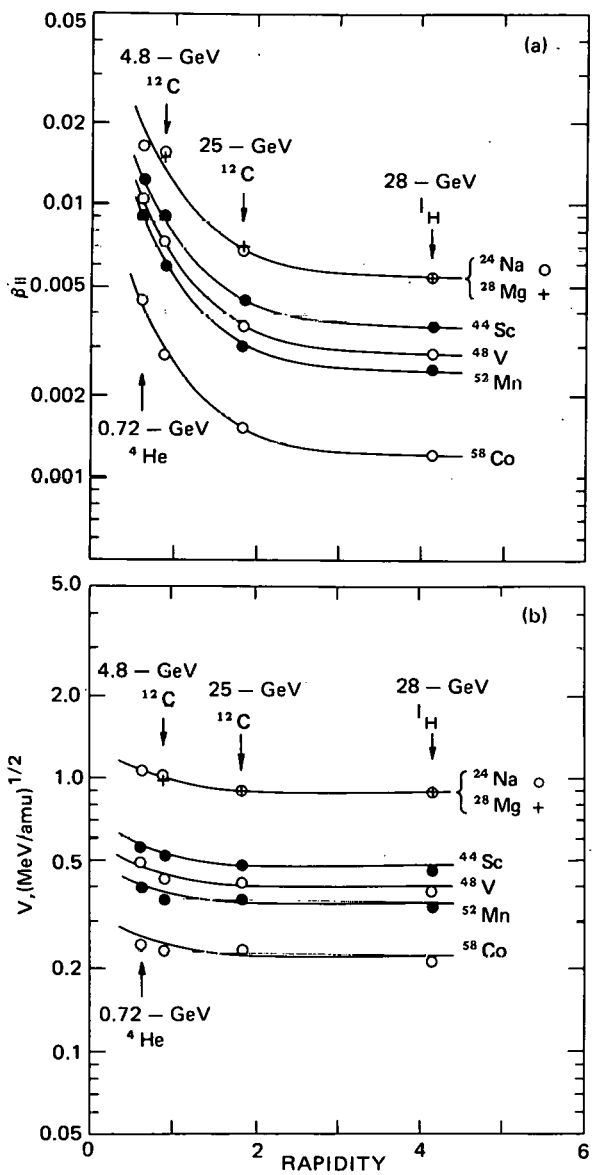


Figure 6. Dependence of $\beta||$(a) and V (b) on projectile rapidity for selected products of the interactions of the indicated projectiles with Cu. All curves in (a) have the same shape except for a vertical displacement. This is also true for those in (b), and shows the nearly universal dependence, except for multiplicative factors, of $\beta||$ or V on projectile rapidity.

tation cross sections should become energy independent and should depend on bombarding particle only via a total cross section term at high energies.

More detailed experiments have now been performed which yield information on the separate steps of target fragmentation reactions. Values of $\beta||$ the forward component of velocity (in units of c) imparted by the abrasion interaction, and of V, the additional component due to the ablation step, are shown in Fig. 6 as a function of the rapidity for representative products of the interactions of various projectiles with copper targets.[10] (Rapidity is a convenient monotonic function of projectile velocity.) Values of V for a given product are seen to be relatively independent of projectile type and velocity, consistent with the limiting behavior inferred previously from yield distributions, which were very similar for 4.8-GeV ^{12}C, 25-GeV ^{12}C, and 28-GeV ^{1}H. On the other hand, values of $\beta||$ vary by a factor 3–4 over this same rapidity range. Thus, the kinematics of the abrasion step for these reactions indicates that deviations from limiting fragmentation persist to substantially higher energies than would have been inferred from measurements of quantities such as product yields or V, which are dominated by effects of the second or ablation step.

Nuclear Spectroscopy

The discovery of two new isotopes highlighted research on the nuclear properties of nuclei far from beta stability. One is a very neutron defi-

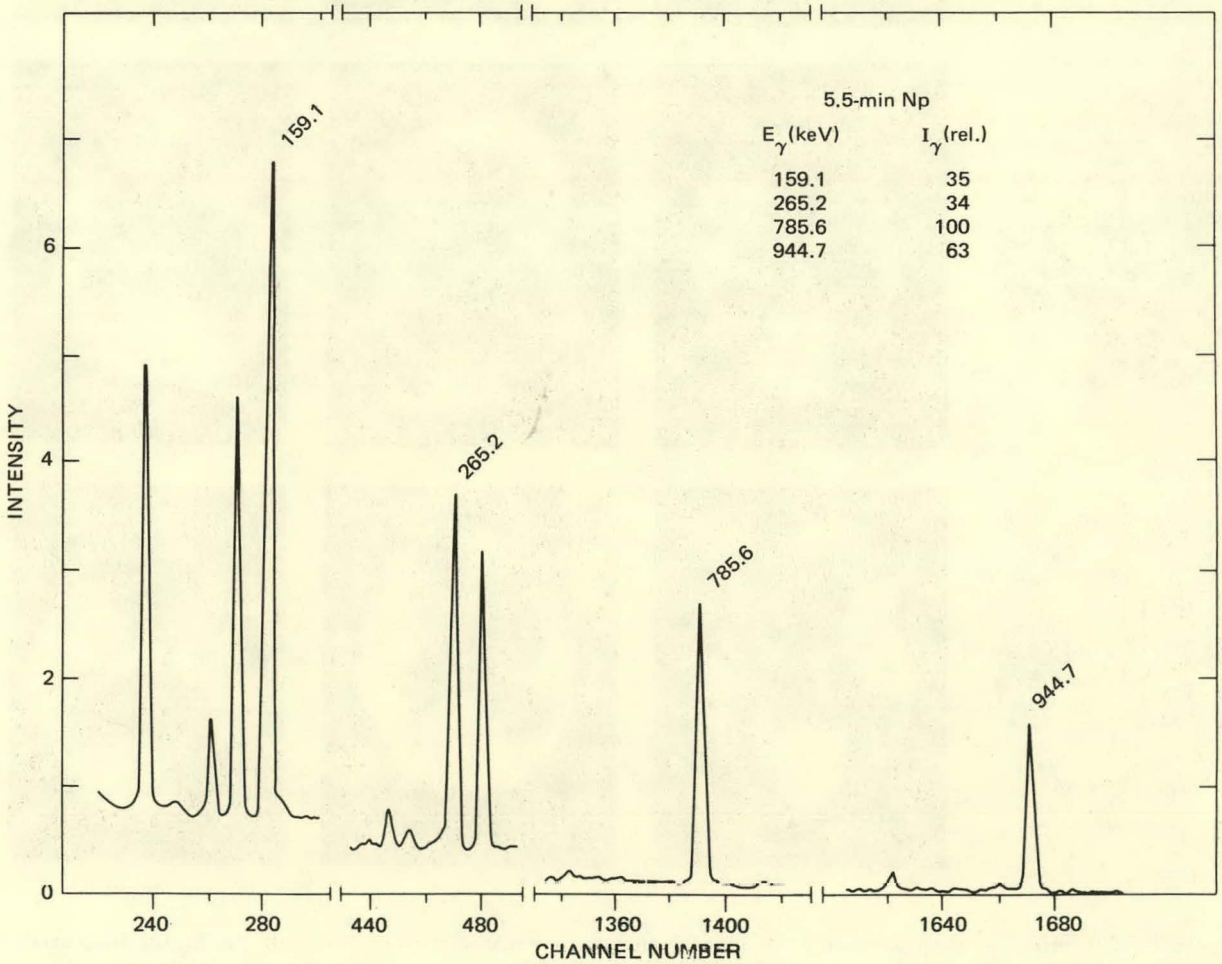


Figure 7. Portions of a γ-ray spectrum showing four peaks from decay of the new 5.5-min Np isotope (probably an isomer of ^{242}Np). The unlabeled peaks are from other neptunium isotopes.

cient isotope of yttrium, 34-sec ^{80}Y, produced at the BNL Tandem Van de Graaff as an evaporation residue from the $^{24}Mg + {}^{58}Ni$ reaction. The other is a neutron-rich isotope of neptunium, half-life 5.5 min, produced by irradiation of ^{244}Pu targets at the Medium Energy Intense Neutron facility, MEIN.[11] Considerable progress was made in elucidating the nuclear decay schemes of these nuclides (Fig. 7) and of several others among the most neutron-rich isotopes of the

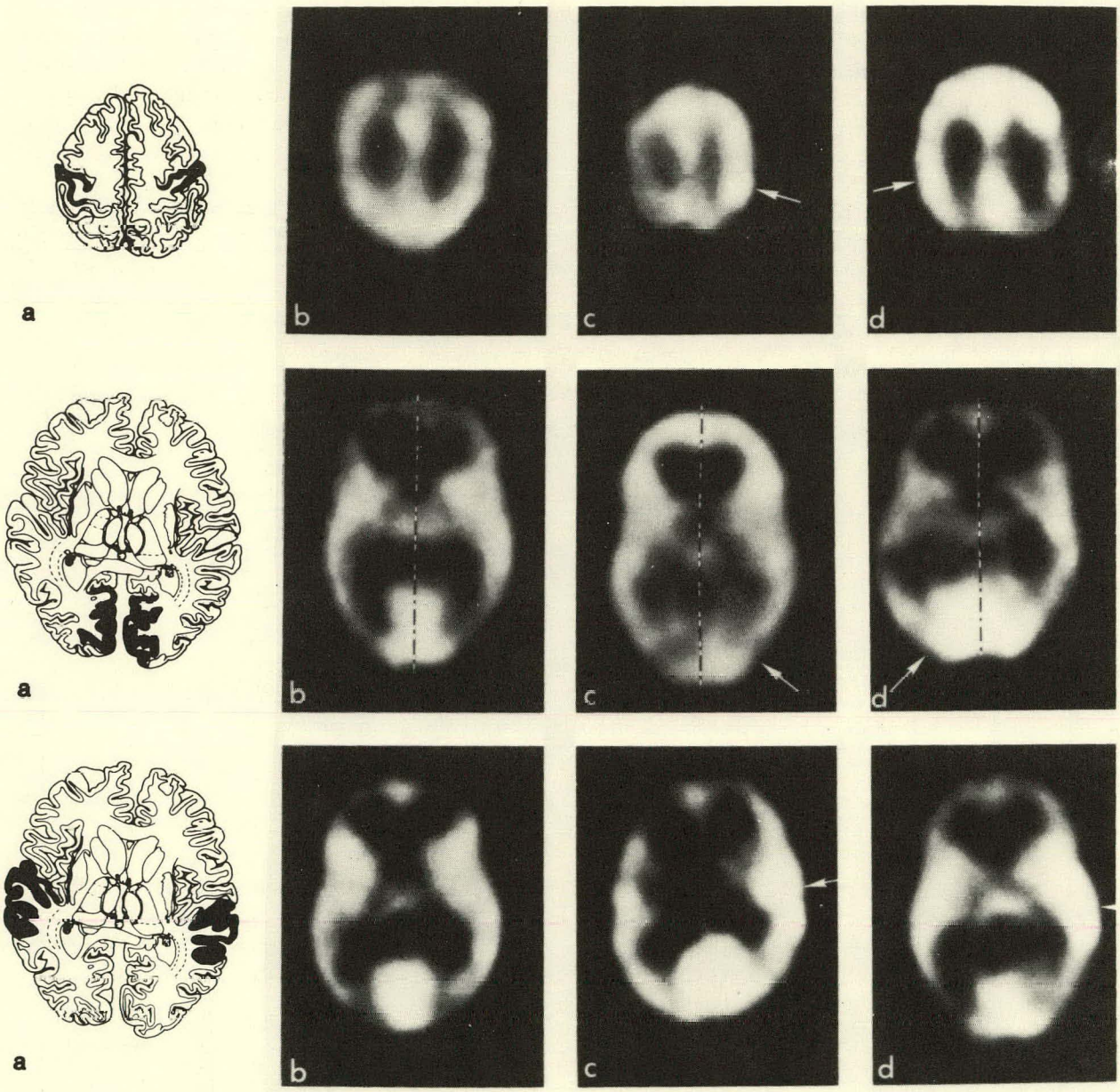


Figure 8. The effect of various stimuli on glucose metabolic rates at various levels of the brain. Increased metabolism is indicated by increased brightness in the pictures. In each row, the line drawing at left represents a level of the brain (with respect to the eye-ear line) and the specific area responsive to an external stimulus is shown in black. Each picture labeled (b) is that of a control subject receiving no stimulation; (c) indicates that the subject is stimulated on the left side, and (d) indicates that the subject is stimulated on the right side. From top to bottom, the rows pertain to tactile stimulation of one hand, visual stimulation of one eye, and audio stimulation of one ear.

heavy elements: 93-min ^{230}Ra, 122-sec ^{230}Ac, 14.1-h ^{240}U, 7.2-min ^{240}Np, 62-min ^{240}Np, and 13.9-min ^{241}Np. Their decay schemes contribute substantially to our understanding of nuclear structure in this important heavy element region.

RADIOPHARMACEUTICAL RESEARCH

The research program in radiopharmaceuticals is currently focused on position emitters such as carbon-11, oxygen-15, nitrogen-13, and fluorine-18, which can be incorporated into materials of medical and biological interest that are known to localize in specific organs or tissues. The new radiopharmaceuticals, used in conjunction with a 3-dimensional scanner, the Positron Emission Transaxial Tomograph (PETT), allow one to probe the dynamics of physiological and metabolic functions in man.

Two of the current investigations under way utilize the radiopharmaceutical ^{18}F-2-fluoro-2-deoxy-D-glucose (^{18}F-FDG). Developed in 1976, ^{18}F-FDG mimics the transport of glucose to brain cells, permitting the measurement of the rate of glucose utilization (metabolism) in specific regions of the brain. A collaborative project with scientists at the University of Pennsylvania was designed to probe the regions of the brain responsible for somatosensory stimulation; i.e., vision, hearing, and tactile sensory perception. (See Fig. 8 and caption.)

The other project (in collaboration with scientists at New York University Medical Center) involves the investigation of neurological disorders such as schizophrenia, senile dementia, aging, Parkinsonism, and Huntington's chorea. This project also involves mapping the visual cortex of the brain, and an attempt to measure changes in the regional brain metabolism of patients before and after cerebral arterial by-pass surgery.

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CHEMISTRY DEPARTMENT
J. Hudis, Chairman

Radiation Sciences and Radiopharmaceuticals

B.H.J. Bielski	C.A. Creutz	R.A. Holroyd	J.M. Preses	H.A. Schwarz	N. Sutin
D.M. Brenner	R.W. Dodson	W.B. Jones	C.S. Redvanly	C.-Y. Shiue	R.E. Weston
B. Brunschwig	R.E. Ehrenkaufer	R.M. Lambrecht	T.J. Ruth	R.W. Stoenner	A.P. Wolf
D.R. Christman	J.S. Fowler	T.L. Netzel	D.J. Schlyer		

Chemical Energy, Analysis, and Separations

M. Andrews	M. Lin	M.L. Perlman	E.V. Sayre	S. Seltzer	T.K. Sham
G. Harbottle					

Nuclear Chemistry

Y.Y. Chu	J.B. Cumming	E.-M. Franz	P.E. Haustein	S. Katcoff	L.P. Remsberg
B.T. Cleveland	R. Davis	G. Friedlander	J. Hudis	E.F. Norton	J.K. Rowley

Chemical Physics

E. Abola	S. Ehrenson	J.R. Grover	T.F. Koetzle	R.K. McMullan	F. Takusagawa
H.J. Bernstein	L. Friedman	J.M. Hastings	W. Kunnmann	J.T. Muckerman	R. Thomas
R.J. Beuhler	J.B. Godel	A.P. Irsa	A. Kvick	M.D. Newton	G.J.B. Williams
L.M. Corliss					

Life Sciences

Biology Department

Medical Department

Biology Department

INTRODUCTION

The exploitation of various energy sources involves potential dangers to health that must be assessed before decisions are made whether or not to expand energy production. Human responses are often delayed and, in the case of toxic materials arising from combustion, so complex and dependent on other influences, such as radiation and ultraviolet light, that current knowledge is not adequate for predicting health hazards. Concerns about cancer, deleterious genetic effects, and disrupted defense mechanisms of the body lead us to seek answers through basic research on cell constituents in order to detect and deal with malfunction.

Biological function can be understood fully only when the molecular machinery has been defined in terms of atomic positions in three dimensions. Structural studies have therefore become increasingly important in the Biology Department, particularly with the development of newer techniques in electron microscopy, nuclear magnetic resonance spectroscopy, and neutron diffraction, that take advantage of the resources of Brookhaven National Laboratory. In these areas, facilities have been developed for use not only by staff scientists but also by visiting academic scientists who would not otherwise have such complex and sophisticated instrumentation at their disposal.

Basic research on plants has long been an important feature of the Biology Department. It is of interest to the Department of Energy partly because photosynthesis is the major biological process for capturing solar energy; a fuller understanding of photosynthesis may permit us to increase its efficiency or devise other methods for using solar energy. In addition, many agricultural practices, including the use of fertilizers, involve sizable energy consumption. Further plant research should lead to increased plant productivity for a given energy expenditure. The association of plant science with the other departmental disciplines encourages collaborative studies with the most up-to-date methods.

MOLECULAR GENETICS

DNA Structure and Function

Bacteriophage T7, a virus that infects the common intestinal bacterium *Escherichia coli*, contains a single molecule of double-stranded DNA. When the T7 DNA molecule enters the bacterial cell, T7 messenger RNAs and proteins begin to be made, and they switch the bacterial cell from making *E. coli* messenger RNAs and proteins to making only T7 RNAs and proteins, followed by new T7 virus particles. The whole process takes only 13 minutes at body temperature, and provides a simple system to manipulate both genetically and biochemically.

The region of T7 DNA expressed early after infection occupies about one-fifth of the molecule and contains almost 8,000 base pairs. An understanding of the principles underlying DNA replication and recombination is being sought by examining mutants of this region that result from deletions — losses of certain portions of the DNA. A combination of biochemical, biophysical, and genetic approaches indicates that deletions arise by crossovers between small repeated base-pair sequences, although computer analyses show that by no means all repeated sequences of six or longer correspond to the ends of known deletions. Nevertheless, three particular deletions that make up the majority of all deletion strains isolated so far apparently come from between repeated sequences of 10, 11, and 13 base pairs. This suggests a relationship between the length of the repeated sequence and the frequency with which deletions arise. With respect to genetic recombination between deletion mutants, preliminary indications are that when deletions are closer together than 50-75 base pairs, recombination frequency is severely depressed. The same rule does not seem to hold for recombination between point mutants (single base-pair changes) and deletion mutants.

Adenoviruses are viruses that cause colds in humans, produce tumors when injected into ro-

dents, and can be grown in cultured human fibroblasts as well as certain monkey tissue cultures. They are slightly smaller than bacteriophage T7, with a double-stranded DNA genome of some 35,000 base pairs coding for about 25 proteins. Recently, the physical locations have been identified, within the DNA, of genes coding for 5 proteins, including 2 proteins involved in the initial transformation of the host cells to the production of more virus particles.

Another powerful method of studying the properties and function of DNA involves bacterial transformation, in which externally added pure DNA brings about changes in the genetic characteristics of the cells exposed to it. It has now been shown that the initial step in the transformation of pneumococcal cells, a binding of the DNA to the outer surface of the cell, entails a single cut in one strand of the double-stranded circular DNA supplied.

DNA Repair

The action of the ultraviolet (UV) radiation in sunlight on DNA can probably account for the majority of the approximately 400,000 new skin cancer cases per year in the United States. In more general terms, the responses of cells to this and other deleterious environmental agents depend not only on the interactions of these agents with cellular macromolecules such as DNA, RNA, and proteins, but also on the way cells cope with the damage. A number of DNA repair processes have been identified. Cells deficient in DNA repair are killed and mutated at lower doses than those proficient in repair. People whose cells are repair-deficient are at least ten times as cancer-prone as the average person. Hence DNA repair is being studied intensively in a number of different experimental systems.

UV radiation is widely used in DNA repair studies because one class of products formed by UV — cyclobutyl pyrimidine dimers — can be identified in several ways, and repair results from excision of these dimers from the DNA. Recently, a bacterial enzyme specific for pyrimidine dimers was used to compare DNA repair in dividing and non-dividing cultures of human fibroblasts. There was no significant difference, suggesting that repair in this system — which may be a good model of human skin — does not depend on active cell cycling. The effectiveness of various UV wavelengths in inactivating non-dividing cultures was also examined, using both a normal cell strain and cells derived from a patient with the disease *xeroderma pigmentosum*. The latter cells are highly repair-deficient, and about seven-fold more sensitive to UV damage. In both, wavelength dependence of the damage is similar to that for the formation of pyrimidine dimers in rodent cells, confirming the view that dimer formation and excision is involved in damage and repair here as well.

In many organisms, UV damage is reversed by visible light acting through a photoreactivating enzyme that splits pyrimidine dimers. The cofactor requirements and substrate specificity of the photoreactivating enzyme from the bacterium *E. coli* are being investigated. A method has been developed to insert that enzyme into cells that lack the ability to photoreactivate in themselves, including certain strains of bacteria and of Chinese hamster cells. This procedure opens many new opportunities for understanding and possibly controlling DNA repair.

In a continuing investigation on the effects of UV on human cells in culture, it has been found that, under special conditions, multiple irradiations can transform the cultured strain to cells having new properties, properties that are probably related to tumor formation. The wavelength dependence of this effect again implicates DNA as the cellular target. Similar transformations are also observed using commercial sunlamps, raising the possibility that this action occurs with longer wavelengths than had previously been expected.

BIOLOGICAL STRUCTURE DETERMINATION

Protein Chemistry

Contraction of muscles is brought about by the interaction of a set of proteins, the major ones being actin and myosin. These molecules apparently underly movement not only in muscle, but in many other types of cells as well, including the alveolar macrophages that remove noxious materials from the lung, and may be involved in certain pulmonary diseases. A basic understanding of cell movement requires knowledge of the structure of the protein molecules responsible. Recently, studies of the structure of one end — the so-called tail — of myosin have been done

using a knowledge of the sequence of amino acids in the protein and computer modeling. The end of the molecule analyzed is known to resemble, in some respects, a two stranded rope, and the computer modeling shows that, contrary to expectation, the pitch of the rope varies along its length. These variations appear to dictate the geometry of the packing of the myosin molecules in muscle.

Proteases — enzymes that attack and split specific portions of various protein molecules — are involved in many basic cell functions. They also participate in important pathological events, such as the formation and dissolution of blood clots, the damage to lung tissue occurring in emphysema, and the metastasis of cancer tumor cells. Recently, a systematic program on synthetic protease inactivators has yielded a compound that has strikingly high activity against the protease thrombin. This activity may prove useful in itself, or in designing other reagents, to minimize widespread clotting during surgery. In a related investigation, the culture of mouse macrophage cells with certain protease inhibitors has resulted in evidence for the existence of a previously unknown protease. The chemical mode of action and cellular role of this enzyme are being investigated.

Neutron Diffraction

The presence at Brookhaven of the High Flux Beam Reactor allowed the development of neutron scattering techniques for the analysis of biological structures. The advantage of using neutrons for the elucidation of biological structures, such as membranes, viruses, protein complexes, and enzymes, rests mainly in the large and significantly different scattering of neutrons by hydrogen and deuterium. Selective replacement of hydrogen with deuterium provides contrasts allowing detailed analysis of structural parameters that were previously obscured. The biological neutron scattering program is carried out by scientists, engineers, and technicians in the Biology Department and the Instrumentation Division, with visiting scientists from many universities.

Hemoglobin, the oxygen-carrying protein of red blood cells, differs between normal persons and those with sickle-cell anemia, a potentially crippling disease. Recently, spectroscopic and neutron-scattering studies of normal and sickle-cell hemoglobin reacted with dichloromethane were conducted, providing new information on the portion of the protein structure responsible for the difference in oxygen-binding capacity between the two hemoglobins.

The purple membrane of halobacteria is a relatively simple biological system in which the energy of visible light is used to produce and maintain a difference in ion concentration between the two sides of the membrane. Neutron diffraction analysis of partially deuterated purple membranes has now made possible the precise localization in three dimensions of retinal — a light-absorbing molecule related to human visual pigments — within the membrane structure. This information is important in understanding the way in which this natural solar-energy device operates.

During the period covered here, a new two-dimensional position-sensitive counter for protein crystallography was incorporated into the spectrometer system. Together with a new software data analysis package, it will reduce by two-thirds the time required to collect data representing a given amount of information.

Scanning Transmission Electron Microscopy

The scanning transmission electron microscope (STEM) at Brookhaven is a state-of-the-art instrument available to biomedical scientists throughout the country. It is the only instrument of its type in the U.S. equipped for low temperature studies on frozen, hydrated specimens, with 2.4Å resolution. The method of image formation is similar to that of a television set, one point at a time, and involves computer processing as well. The photograph of a DNA molecule shown in Fig. 1 was recently obtained with this instrument.

Recently, measurement of mass with the STEM has been established as a technique with less than 1% error. The technique depends on the relationship between the electron-scattering power of the specimen and its molecular weight. It can determine mass per unit length and mass distribution, either within single molecules or more complex structures. In collaboration with investigators from other institutions, as well as from BNL itself, this technique has been used in work on filamentous viruses, DNA repair enzymes, and the interaction of fibrinogen molecules to form fibers, to give only a few examples.

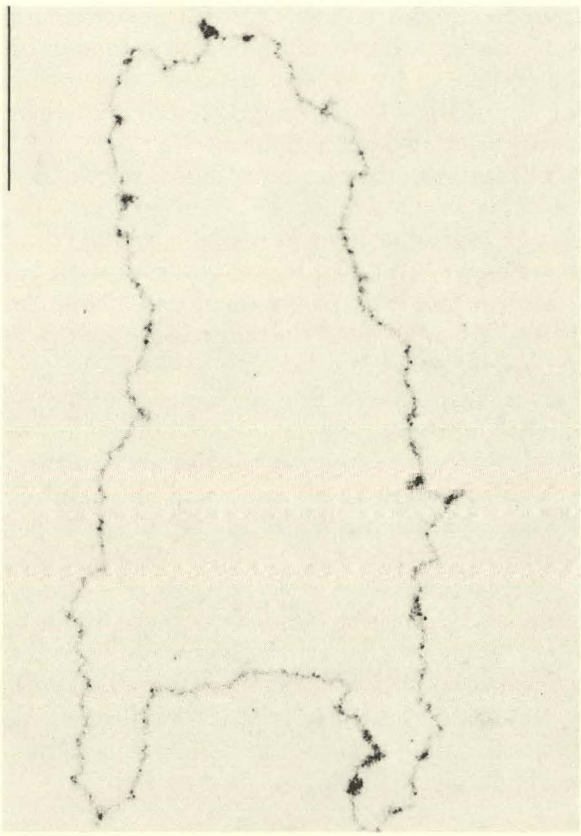

Figure 1. Double-stranded circular DNA from fd bacteriophage. The adenine bases of the DNA are labeled with a tetramercury compound, and appear as small black dots. The scale bar is equal to 0.1 μm. Work carried out on the Brookhaven Scanning Transmission Microscope — an NIH Biotechnology Resource — in collaboration with S. Lippard and J. Lipka, Columbia University.

Among the major goals in STEM research is the development of a comprehensive theory of the relationship between the STEM image and the conformation of the specimen, a relationship that necessarily depends on many parameters. Recently, a model has been devised that permits accurate predictions — differing from previous theoretical calculations — of the signal-to-noise ratio actually obtained under particular conditions. This model makes it possible to optimize the various experimental variables and understand trade-offs between them.

Synchrotron Ultraviolet Project

The first phase of the Synchrotron Ultraviolet Project for Experimental Research in Biophysics has been constructed, with the configuration shown in Fig. 2. The equipment is presently operating at the National Bureau of Standards synchrotron in Maryland, where it has already yielded preliminary data on protein and nucleic acid structure. It will be moved to the National Synchrotron Light Source at Brookhaven as soon as the latter is completed. Measurements of circular dichroism, magnetic circular dichroism, and fluorescence spectra — all powerful tools for the elucidation of molecular structure and dynamics — use to great advantage the high intensity, broad spectral range, polarization, and small source size of synchrotron radiation, as well as the fact that it is produced in discrete pulses.

BIOENERGETICS AND PLANT SCIENCES

Photosynthesis

Light energy absorbed by pigments in the chloroplast thylakoid membrane drives photochemical reactions that lead to the separation of charge and development of an electrical field across the membrane. Some of the potential energy of this field is trapped in subsequent electron transport processes, and provides energy for carbon fixation. Photosynthetic charge separation and electron transport are thus being investigated to obtain fundamental knowledge with respect to plant biomass production, and with a view to utilizing some of the underlying principles to devise a water-desalting process powered directly by solar energy rather than using conventional electrodialysis.

Rapid events in intact or osmotically shocked spinach chloroplasts are being followed by fluorimetry, flash spectroscopy, and pH- and O_2-sensitive electrodes. It has now become clear from numerous observations that cyclic electron flow in intact higher plant chloroplasts is similar in many respects to the electron transport pathway in mitochondria and to that found in the photosynthetic electron transfer system of the purple non-sulphur bacteria. An additional significant finding has to do with the kinetics of a newly-observed electrochromic effect — a rise in absorption at 518 nm — in relation to that of other events immediately following illumination. The results suggest the existence in cyclic electron flow of an electrogenic step other than the one already recognized.

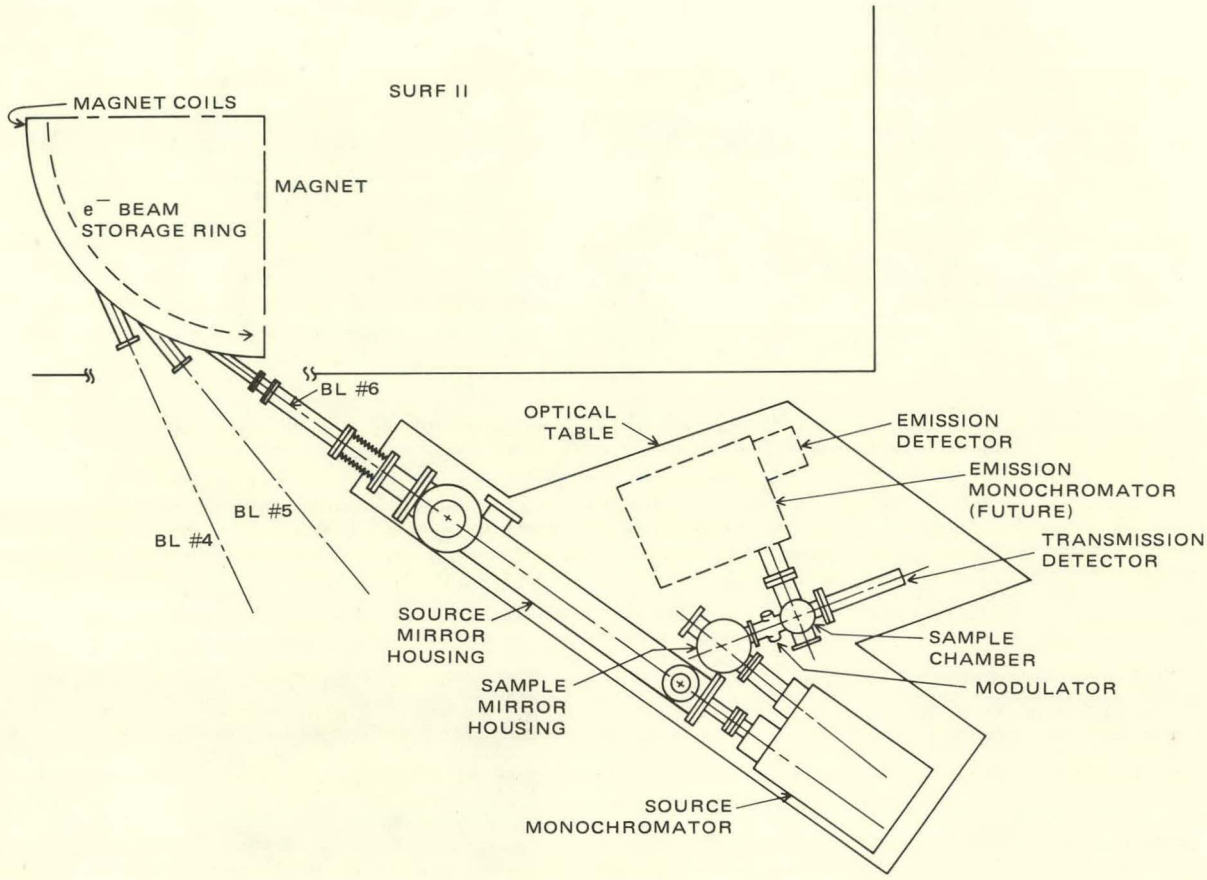

Figure 2. Diagram of the first phase of Brookhaven's equipment for using synchrotron radiation to study the structure of biologically important molecules (see text). It is currently operating at the National Bureau of Standard's SURF (Synchrotron Ultraviolet Users' Facility) in Gaithersburg, Maryland, and will be moved to BNL when the National Synchrotron Light Source is complete. BL stands for beam line.

Other departmental programs concerned with photosynthesis are represented by Figs. 3 and 4.

Cytogenetics and Genetics

Basic studies on the replication of DNA in plants have focused on two questions — the size of the replicating units, called replicons, and the rate at which these replicons are duplicated, the so-called "fork-rate." Plant species representing an 80-fold range of DNA per cell were examined, with the notable result that both replicon size and fork rate were similar in all. Fork rates are appreciably lower in plant cells, however, than in either bacterial or mammalian cells. The similarity of replicon properties among many species of plant cells represents a welcome simplification for research on chromosome structure, the control of cell division, and mutagenesis in plants. These results are also significant in arguing for a conservation of DNA replication characteristics in plant evolution.

The use of *Tradescantia* to monitor atmospheric pollutants is an example of practical genetic research. Certain clones have a dominant blue gene and a recessive pink one for flower color. Lesions (mutations) in the blue gene result in a readily observed change to pink in the cells of the stamen hairs. Under carefully controlled conditions, using a mobile laboratory, these color changes have been used over the past few years to monitor air in various parts of the United

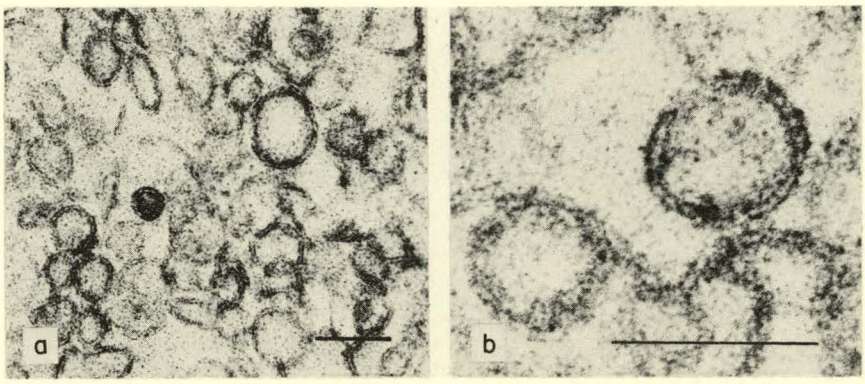

Figure 3. Electron micrographs of a thin section of unit-membrane vesicles from *Chlorobium limicola* f. *thiosulfatophilum*, a green photosynthetic bacterium. Vesicles were formed from the cytoplasmic membrane during cell breakage and contain lipids, bacteriochlorophyll-l-proteins, photochemical reaction centers, cytochromes, carotenoid, and quinone. They are being used to demonstrate photoproduction of hydrogen gas from weak hydrogen donors such as ascorbic acid, with a view to developing a photochemical system that produces hydrogen from water. The scale bars in the micrographs are 100 nm long.

States for mutagenic chemicals. However, some residual concerns had remained with respect to the truly genetic nature of the color change. A series of breeding experiments has now essentially removed those concerns, greatly strengthening the significance of results obtained with this system.

The biochemical genetics of maize (corn) is obviously of practical significance. Furthermore, fundamental genetic information on this plant includes the classic work of Barbara McClintock, the first fully convincing evidence in any organism that transposable controlling elements modulate the actions of genes of which they themselves are not parts. Recently, studies with nucleic acid cloning techniques have compared the structures of the *Shrunken-1* gene (coding ultimately for the enzyme sucrose synthetase) and an unstable mutant allele. The latter appears to reflect the action of a transposable controlling element. Only a single DNA species is present in the wild-type gene, in contrast to a number of molecules with different lengths in the homozygous mutant allele. This supports a view long suggested but never proved: that the controlling element is inserted directly at the locus modulated.

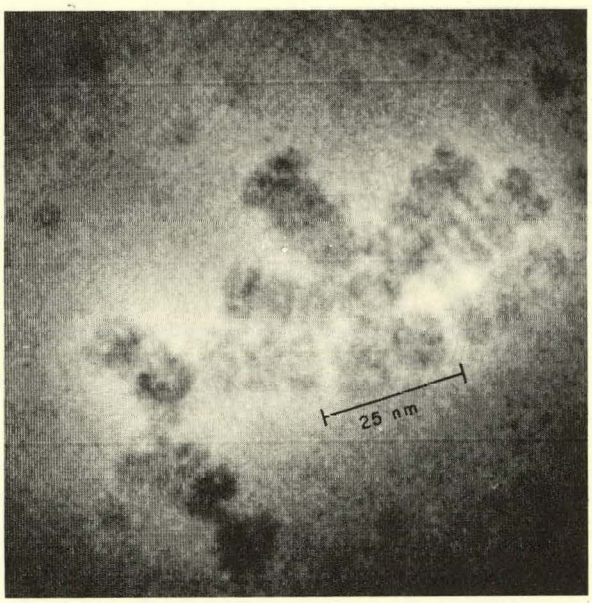

Figure 4. Blue-green algae use solar energy collectors called phycobilisomes for photosynthesis. Phycobilisomes are supramolecular aggregates of brightly-colored proteins, and they can be observed in the scanning transmission electron microscope. They consist of six arms composed of four discs and a central core of three discs. They collect solar energy in regions of the spectrum where chlorophyll is not an effective absorber, transferring energy to chlorophyll to initiate photosynthesis. These studies provide information on the molecular structure, composition, and function of natural solar energy collectors. The scale bar is equal to 25 nm.

Plant and Cell Physiology

Not only are plants capable of detecting pollutants, but they may also serve as sources of haz-

ardous substances in the food chain. This is so because they can accumulate chemicals from the environment and store them in various regions of their cells. With the object of understanding such situations better, the fate of cadmium, a toxic metal, accumulated in various plants is being examined. Contrary to previous expectations, most of the cadmium within the cells appears to be localized in the cytosol and cytoplasmic particles. In addition, fully 80-85% of the cadmium taken up is not, strictly speaking, accumulated within the cells at all, but is held in the plant cell walls. The cellular distribution of zinc ions seems to be similar to that of cadmium, but nickel ions, in contrast, do accumulate to a substantial degree in the vacuole, possibly as the citrate.

* * *

Because of space limitations, not every group in the department has been represented in this account, nor are the approaches and results of any considered in detail. For additional perspectives on department activities, see the descriptive departmental roster and the following bibliography, selected from the more than 120 articles published or accepted for publication during the period October 1, 1978 — September 30, 1979. Most of these articles necessarily cover work done earlier than the most recent developments reported above.

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BIOLOGY DEPARTMENT

Richard B. Setlow, Chairman
Geoffrey Hind, Deputy Chairman

Molecular Genetics

Carl W. Anderson
Organization and expression of the adenovirus genome.

John J. Dunn
Synthesis and processing of RNA in *E. coli* and its phages; role of RNase III in RNA processing.

Sanford A. Lacks
Mechanism of genetic transformation in *S. pneumoniae*; function of DNases.

Jane K. Setlow
Transformation, recombination and repair in *H. influenzae* and its phages.

Richard B. Setlow
Damage to DNA by radiation and chemical carcinogens and its repair.

F. William Studier
Genetics and physiology and bacteriophage T7; gene expression, DNA metabolism, phage assembly.

Betsy M. Sutherland
DNA repair; cellular level photobiology.

Biological Structure Determination

R. Douglas Carlson
Neutron scattering studies of chromatin and histone complexes.

Marshall Elzinga
Muscle and microtubular protein chemistry

James F. Hainfeld
High resolution microscopy of membrane components. Reconstruction from ordered arrays.

Paul V. C. Hough
Use of fluorescence electron microscopy to localize individual molecules in cellular organelles.

Anthony A. Kossiakoff
Protein crystallography by neutron and x-ray diffraction.

Alan C. McLaughlin
High resolution NMR studies of complexes between small molecules and macromolecules. Membrane structure.

Benno P. Schoenborn
Neutron diffraction of biological structures; ribosomes, membranes.

Elliott N. Shaw
Structure and function of cellular and blood proteases; enzyme chemistry.

John C. Sutherland
Optical probes of macromolecular conformations and interactions.

Joseph S. Wall
High resolution scanning transmission electron microscopy and single atom staining of filamentous viruses.

Bioenergetics

Geoffrey Hind
Photosynthetic electron transport and phosphorylation; ion fluxes in chloroplasts and plant cell vacuoles.

John M. Olson
Structure of the photosynthetic unit of green bacteria.

Myron C. Ledbetter
Fine structure of plants and plant cells by electron microscopy.

Plant Sciences

Benjamin Burr; Frances A. Burr
Biochemical genetics and storage protein synthesis in maize.

William S. Hillman
Control of growth and metabolism by light; aquatic plants for pollutant removal and biomass production.

Lloyd A. Schairer
Plant mutagenesis.

Daniela Sciaky
Genetic engineering in plants.

H. William Siegelman
Phytoplankton physiology and biochemistry.

Harold H. Smith
Use of cell and tissue culture in plant cell genetics.

Jack Van't Hof
Genetics and regulation of the plant cell division cycle.

George J. Wagner
Characterization of plant cell vacuoles; mechanisms of accumulation in plant cells.

At the close of Fiscal 1979 some 14 postdoctoral Research Associates, some supported by outside grants or fellowships, were contributing to the research efforts of several of the groups listed above.

Medical Department

INTRODUCTION

Since 1949 the Medical Department has carried out research directed toward the better understanding, diagnosis, and treatment of human disease. Now, with funding principally from three federal agencies (Department of Energy, Environmental Protection Agency, and the National Institutes of Health), the main emphasis of research is concerned with effects of environmental pollutants related to energy production on human health.

Four major themes represent the scientific effort of the Department, Environmental Health Sciences, Nuclear Medicine and Medical Physics, Genetics and Biochemical Sciences, and Host Defense Sciences. These programs complement and interrelate with each other by collaborative effort. This is especially true for our program in inhalation toxicology which is a major project in the Environmental Health Sciences program. The efforts here are directed toward effects on human beings as well as animals, and are concerned with pollutants derived from energy technologies in the form of gases, and chemical or particulate aerosols. The clinical aspect of the program is closely tied to work in the Nuclear Medicine and Medical Physics program in which nuclear techniques are developed for early diagnosis.

Continuing surveys of certain Marshall Islands populations are made in an effort to determine any ill effects these people may have suffered as a result of accidental exposure to radiation. Connected with this program is a limited delivery of health care to these people.

New radiopharmaceuticals are developed at Brookhaven using special and even unique facilities which enable production and use, in our clinical facility, of short-lived isotopes incorporated into organic molecules which make visible, by means of unusual instrumentation, anatomic features and functional capacity of various organs. Instrumentation is developed for *in vivo* determination of the elemental composition of the human body or selected organs. Thus, renal concentrations of cadmium are determined. Total-body nitrogen, calcium, sodium, potassium, and chlorine are determined using *in vivo* neutron activation techniques and a unique whole body counter. Organ-specific determinations of iron, silicon, and beryllium are now being developed and will be of great importance to the detection of these pollutants in the human body.

Basic mechanisms, screening techniques, and synergistic effects of pollutants which lead to mutagenesis, carcinogenesis, and teratogenesis are investigated and related to effects seen in studies of chronic or acute animal exposures, and to clinical diagnoses made of persons exposed to environmental pollutants.

A physiological barrier to disease, the body's defense mechanisms, and the effects of pollutants on the effectiveness of these natural defenses are studied in the Host Defense Sciences program. Using sheep or small animals, effects of inhalation of energy-related pollutants on the lympho-hemopoietic system are investigated. The morphological and physiological integrity of these systems are related to exposure, dose, and kind of pollutant. Again, this information is related to the effort in pulmonary toxicology. The fate and effects of particulate pollutants penetrating the gastrointestinal tract are aspects of another related study.

The major clinical effort which will be of importance for guidance of energy technology design and direction is focused on coal workers' pneumoconiosis. This project will begin in FY 1980. The interaction with the above-mentioned programs is obvious and intentional. It is this interaction of applied, basic, and clinical research which is the strength of the program of the Medical Research Center.

The following report, although brief, gives some idea of the types of work being done. Additional information may be obtained from publications of the Department.

PULMONARY PROGRAM

The pulmonary program in the Medical Department consists of two broad areas of re-

search: One devoted to clinical studies in humans, and the second devoted to investigating the toxicity of inhaled materials in animals. With regard to our clinical programs our immediate goals are to develop more sensitive techniques for assessing human pulmonary disease. These studies are performed in healthy individuals and in patients with a variety of respiratory diseases at the Hospital in the Medical Research Center. Our hospital contains the most modern facilities and equipment available for assessing respiratory function in humans. We can conduct standard pulmonary function tests using nuclear medicine techniques which include the use of radioactive tracers in inspired gases and the use of tracers in pulmonary blood. These techniques provide a more sensitive and accurate measurement for assessing early damage of small airways and the terminal units in the lung.

The increasing use of coal to provide for our energy needs in the next decades will result in more people being employed by the coal industry with the consequent potential for exposure to coal dust. The mining of coal has long been recognized as an occupational hazard resulting in coal workers' pneumoconiosis. A high percentage of miners retire early and receive some form of workman's compensation due to their occupationally-sustained lung diseases. The increasing use of coal either directly or in the production of synthetic fuels is bound to increase the potential for atmospheric pollution. Thus, it is important to design experimental studies which can identify specific populations that are susceptible to increased concentrations of air pollutants. It is also useful to develop animal models of human pulmonary disease in order to determine why and how susceptible individuals react to exposure to air pollutants.

One of the major goals in our clinical program is to determine the symptoms and measure changes occurring in miners exposed to coal dust and to correlate these findings with the degree of exposure. It is important that both coal workers' pneumoconiosis and progressive massive fibrosis be investigated in order to understand the causes of these disorders and to intervene, where possible, to reverse the progression of these diseases. Thus, a comprehensive study of coal workers' diseases has been designed and final approvals are being sought. This study will be performed in collaboration with Marshall University, the Appalachian Pulmonary Laboratory, and the University of California. A respiratory questionnaire has been developed for collecting information on specific respiratory symptoms, age, sex, smoking habits, occupational exposures, and residence.

Another project in the clinical program is the investigation and quantification of the deposition, translocation, and removal of inhaled particles in the lungs of man. These studies use particles tagged with radioisotopes, and a gamma camera to provide high resolution images of particle distribution *in vivo*. Alveolar clearance of small amounts of radioactive material can also be measured for more than a year using the whole body counter. Current results indicate that there are two phases of long term clearance in healthy individuals having half-times of approximately 30 and 300 days, respectively. This is the first time that this biphasic clearance has been demonstrated in man. With regard to animal studies, an inhalation toxicology laboratory has been constructed over the last three years to permit exposure of animals to highly hazardous airborne chemicals. Figure 1 shows the new inhalation toxicology laboratory as an addition to the Medical Department. This laboratory is equipped with two large chamber rooms (Fig. 2) with equipment for exposing animals to a variety of airborne materials.

While waiting for the completion of the new laboratories, several studies were conducted in interim facilities. In one series of studies we are investigating the relationship between the development of hypertension and exposure to common air pollutants, specifically whether exposure to energy-related air pollutants alters the development of hypertension in an animal selected to develop high blood pressure as a result of both genetic and environmental factors. Two such studies have been completed, one with sulfur dioxide and one with ozone. The results with sulfur dioxide suggest that the relationship between sulfur dioxide and the development of hypertension is minimal.

The results with ozone are far more interesting. Two lines of rats which differ in their tendency to develop hypertension when fed a diet with a high concentration of sodium chloride were used. The susceptible animals are designated "S", in contrast to "R" animals which are resistant to salt-induced hypertension. When

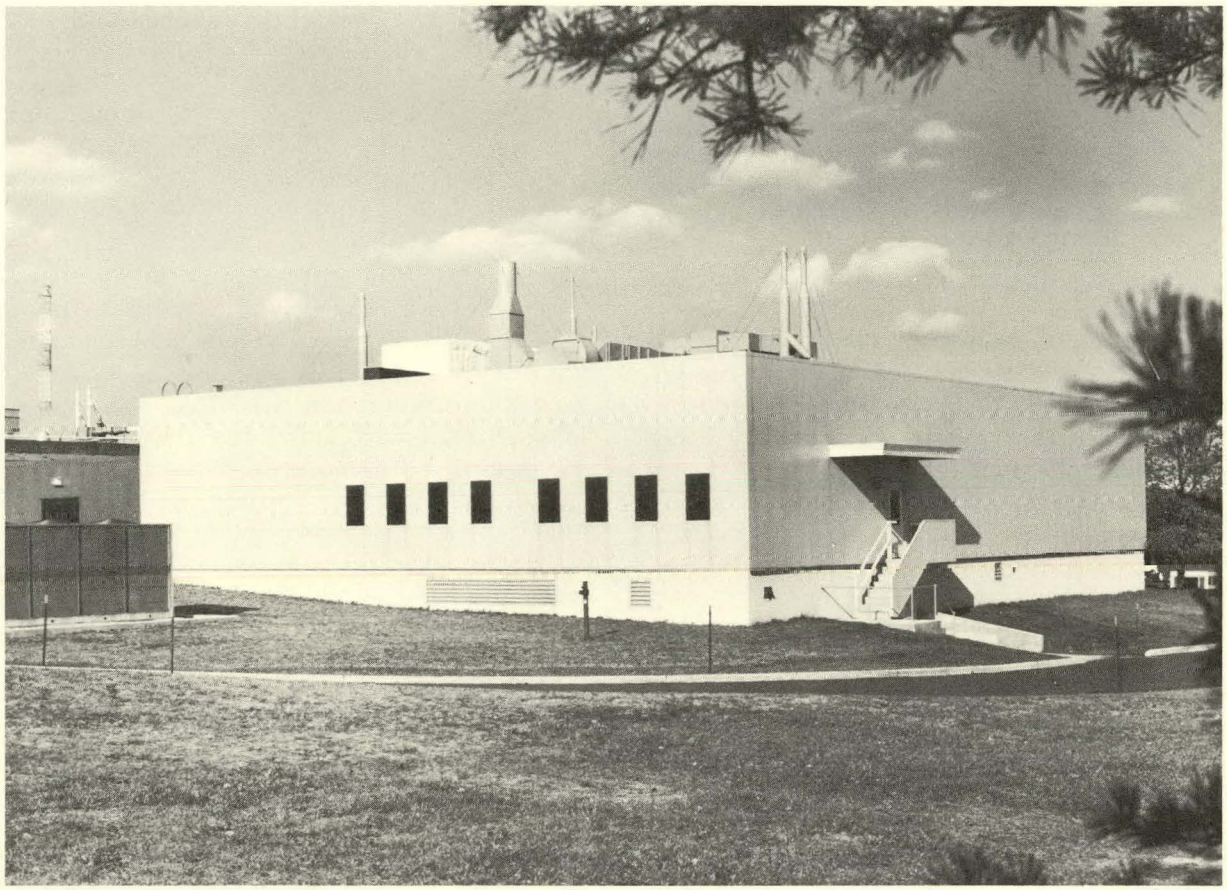

Figure 1. View of the new inhalation toxicology laboratory building.

"S" animals are exposed to two parts per million ozone, they die approximately 12 weeks after the beginning of the exposure. regardless of the concentration of salt in their diet. (Fig. 3). The reasons for the susceptibility of the "S" animals to ozone toxicity are not known. However, the differences between the "R" animals and the "S" animals may be extremely valuable to an

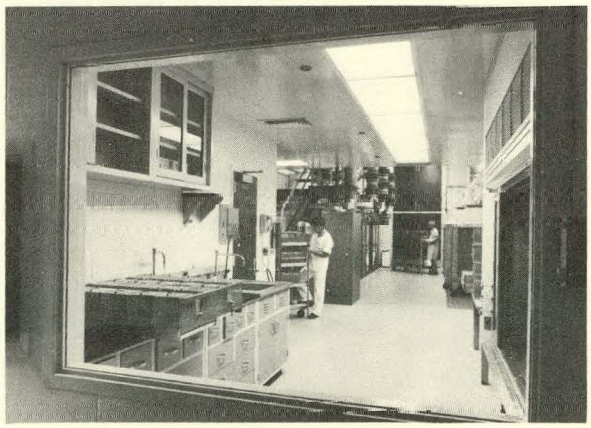

Figure 2. One of the two large chamber rooms.

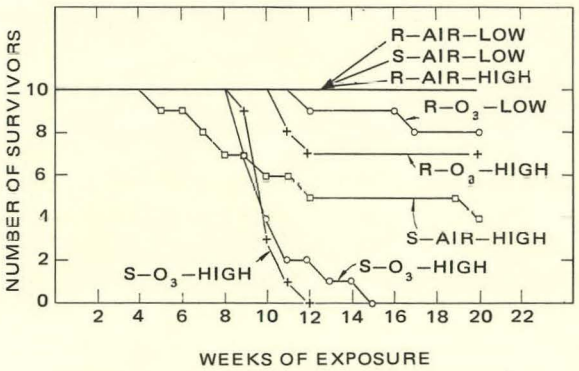

Figure 3. Survival curves of "S" and "R" rats on high or low salt diets exposed to air containing 2ppm of ozone (O_3). Controls were exposed to air.

understanding of how ozone exerts its toxic effect. Studies in this direction are currently underway.

Another study is concerned with the behavior of glass fibers when introduced into the respiratory tract of rodents. Several years ago it was shown that the peritoneal installation of glass fibers could produce tumors similar to those produced by asbestos in the peritoneal cavity of rats. It was subsequently determined that the actual physical size, the diameter and the length of the glass fibers, played a critical role in the development of these tumors. Therefore, we are investigating the behavior of sized glass fibers, when introduced to the respiratory tract, as a function of both the length, the route of administration, and the time after administration. Figure 4 is a photomicrograph of the lung of a rat which had been instilled with 1.5 x 60 μm fibers eight months prior to sacrifice. We believe the glass fiber shown is surrounded by pulmonary macrophages which are making an attempt to remove it. It is thought that the inability of macrophages to remove these long narrow fibers is related to the process whereby these specific sized fibers can produce mesotheliomas. The outcome of these studies will allow us to better understand how the lung handles small fibers and hopefully to know if the presence of these fibers in the lungs of animals will lead to the development of mesotheliomas.

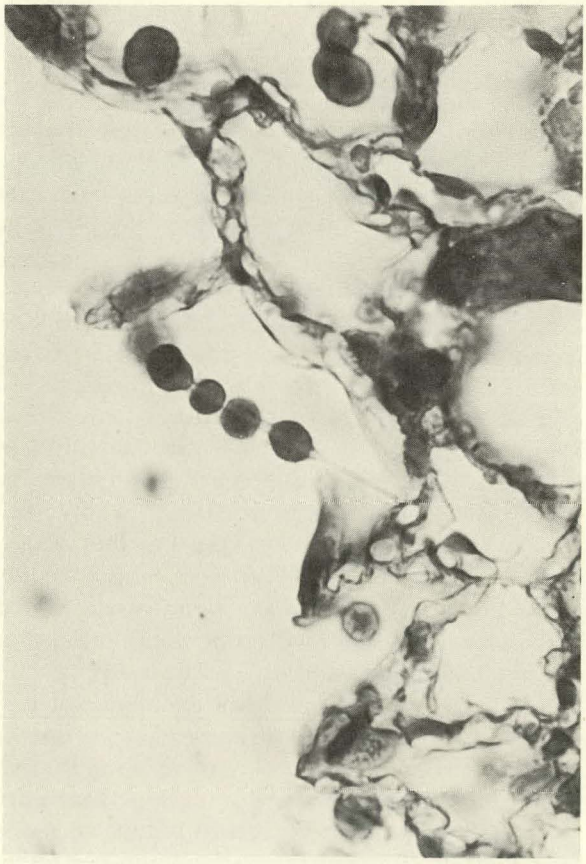

Figure 4. Photomicrograph of a rat lung with a 1.5 x 60 μm glass fiber in it. Apparently macrophages are attempting to remove the fiber.

EFFECTS OF ENVIRONMENTAL POLLUTANTS ON LUNG DEFENSE MECHANISMS

Local expression of pulmonary immune responses is vital to the protection of the host against a multitude of inhaled microorganisms. To what extent immunologic reactions in the lung are altered by inhalation of atmospheric pollutants is not fully understood. This problem is currently being studied using sheep in which a major lymph duct draining the lungs is cannulated. The lymphatic system, including lymph nodes, is vital for full expression of the immune response; therefore, continuous monitoring of lymph coming from antigenically challenged lung tissue is a sensitive method to assess the effects of inhaled pollutants on a critical aspect of the pulmonary defense mechanism. Figure 5 illustrates the results of one of the assays em-

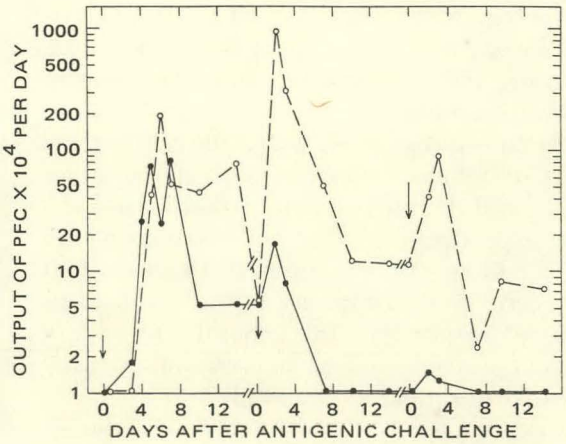

Figure 5. Daily output of 'direct' (●—●) and 'indirect' (o- -o) plaque-forming cells from the caudal mediastinal lymph node following the intrabronchial administration of red blood cells as antigen. Three challenges (arrows) with intervals of 18 and 14 days were given.

ployed in these studies. Antibody-producing cells can be easily detected on a glass slide by their ability to lyse red blood cells provided the antigen used for immunization is either the red blood cells themselves or red blood cells coated with the specific antigen. Such cells, called plaque-forming cells, appear in pulmonary lymph in a predictable magnitude and pattern. The difference between "direct" and "indirect" plaque-forming cells is in the type of immunoglobulin (Ig) produced by the cell. "Direct" plaque-forming cells secrete IgM while "indirect" plaque-forming cells secrete either IgA or IgG. The influence of NO_2 exposure on pulmonary lymph antibody-forming cells, as well as other parameters of pulmonary defense is currently being studied.

BENZENE INHALATION EFFECTS ON ANTIBODY RESPONSES AND LEUKEMOGENESIS

Intense national interest has been given to the concentration of benzene to which workers and the general population may be exposed on a daily basis. The Labor Department's Occupational Safety and Health Administration (OSHA) has recommended lowering the present daily standards of 10 ppm to 1 ppm. The industrial use of benzene continues to increase each year. More than 5×10^9 liters of benzene are used annually by chemical industries for the synthesis of more complex chemicals and plastic materials. Benzene and closely related chemicals are now being added to gasolines to replace lead as anti-knock agents.

This study is concerned with acute and chronic effects of inhaled benzene upon immune responses and the incidence of leukemia in mice. Initial exposure of mice to benzene vapor (400 ppm) for 6h/day for periods of 5, 10, 20, and 30 days increasingly suppressed primary tetanus antibody responses. In general, secondary (booster) antibody responses were only slightly repressed in similarly treated mice.

An experiment was carried on to test the effects of inhaled benzene (200 ppm) upon primary antibody responses to fluid tetanus toxoid (FTT) and/or adsorbed tetanus toxoid (APTT). Groups of mice (15/group) were exposed for 5, 10, or 20 days prior to immunization. Similar groups were maintained under air chamber control conditions. Primary antibody responses to FTT were increasingly suppressed in mice exposed to benzene for periods of 5, 10, and 20 days. Primary responses to APTT were not altered after 5 days of exposure to benzene, however, exposures of 10 and 20 days increasingly suppressed antibody production. It should be noted that exposure of mice in air chamber control situations also resulted in reduced antibody responses, however, antibody production was not suppressed to the levels observed after exposure to benzene vapors.

Chronic exposure of man to benzene has been closely related to depression of the bone marrow with subsequent development of aplastic anemia. The appearance of leukemia in man has long been believed to be related to chronic exposure to benzene. Actual exposure doses for man have been difficult to determine, the doses vary from about 100 to above 400 ppm over a period of many years. There is no direct evidence at present for benzene as a leukemic agent in laboratory animals. This study is designed to test the myelotoxic and leukemogenic potential of inhaled benzene (300 ppm) upon the time of onset and incidence of lymphocytic and myelocytic leukemia in genetically defined mice. Two principal genotypes of the HRS/J strain are now available for study. The (hr/hr) hairless mice are leukemia-prone (80-90% incidence). The (hr/+) genotype is more resistant to leukemia (10-20% incidence). The use of the inbred HRS/J strain of mice provides a unique biological tool to test the leukemogenic effects of chronic exposure to benzene. All HRS/J mice carry equivalent amounts of murine leukemia virus in their tissues. They differ only in one gene (hr) on chromosome 14 (linkage group III). The (hr) locus is believed to be involved in susceptibility to leukemia. Previous studies have demonstrated that exposure of these animals to ionizing radiations (sublethal doses) and/or immunosuppressant chemical agents increased the incidence of leukemia in (hr/+) mice and hastened the time of onset of leukemia in (hr/hr) mice. Exposure of mice to ionizing radiations, immunosuppressant agents, and benzene greatly inhibits antibody production. It remains to be determined if exposure to inhaled benzene (300 ppm) increases the time of onset and/or incidence of leukemia in HRS/J mice.

ENVIRONMENTAL, HEALTH, AND SAFETY ASPECTS OF PHOTOVOLTAIC TECHNOLOGY

The growing use of photovoltaic devices in energy production poses new questions regarding possible health effects of this technology to the general public. Obvious hazards will be eliminated in the design stage and hence constitute no real problem. [Examples include misdirection of a concentrator (mirror or lens), overheating of a concentrator from loss of coolant, and scattered or misdirected microwaves from a solar power satellite.]

The photovoltaic (PV) devices that convert sunlight directly into electricity are semiconductors which produce a voltage and, if connected to a load, an electric current, when sunlight falls on them. Most PV cells contain at least one chemical element which either is known to be toxic (e.g., arsenic or cadmium) or about which only little health-effects information exists (e.g., indium or gallium). These elements vary in concentration from a few parts per million to major fractions of the matrix.

The Department of Energy is anxious to ensure that potential hazards are identified at a stage sufficiently early to permit their elimination either through devising a satisfactory solution or through redirecting the technology development.

The overall objective of this program is to assist the development of PV technology with maximum safety to workers and to the public at large. Specific objectives include identification of existing or potential PV environmental, health, and safety (EH&S) problems, identification of missing information needed to quantify such problems and specific areas in which PV EH&S research is needed, definition of a program to accomplish this additional research and recommendation of appropriate priorities, development of a systematic quantitative biomedical/environmental cost assessment of energy production via PV systems, and comparison with similar assessments for other energy technologies.

The management and coordination of this program is provided on a continuing basis by the BNL Medical Department. Specific tasks are carried out by appropriate groups in various departments at BNL and elsewhere.

A workshop on the Health Effects of Photovoltaic Technology has been conducted which brought together specialists representing a broad spectrum of disciplines. The results of this workshop are being used to define a program of needed health-effects research, and the proceedings are being published.

A second smaller workshop to concentrate on environmental effects of PV technology is being planned for June 1980.

The Biomedical and Environmental Assessment Division (BEAD) of the BNL Department of Energy and Environment is actively collecting data with which to begin its assessment of the biomedical costs of energy production via PV systems. Similar recently completed assessments for other energy technologies will facilitate their comparison with PV technology.

OXIDATIVE AND FREE RADICAL MECHANISMS INVOLVED IN TOXICITY OF POLLUTANTS

The oxidants ozone (O_3), nitrogen dioxide (NO_2), and sulfur oxides (SO_x) are common(?) pollutants known to have deleterious effects in man. However, the mechanisms by which these compounds damage cells and tissues are not clearly understood. At least three sources of damage potential are recognized:

1) Direct reaction of the pollutant or its breakdown products.

2) Reaction of the pollutant or its products with lipids of cell membranes to initiate formation of lipid free radicals and peroxides which, in turn, attack other molecules both in membranes and inside the cell.

3) Reaction of either the pollutant or the oxidizing lipids with phagocytic cells (macrophages and granulocytes) in the lung, leading to impaired bacterial clearance and decreased resistance to infection and, possibly, to elaboration by the phagocytes of toxic substances associated with inflammation.

The principal focus of this program is to clarify the nature and extent of involvement of each of these three pathways in lung pathology and in extra-pulmonary (systemic) effects caused by exposure to oxidizing pollutants.

Reactions and Interactions of Oxidizing Lipids

The free radical intermediates formed during the oxidation of lipids are usually short-

lived, and thus detection and study of these species present some problems. Two special electron paramagnetic resonance (EPR) techniques have been developed that will facilitate investigations of short-lived radicals.

In continuous flow EPR, radicals are continuously generated as reactants, mechanically forced through separate lines, and mixed immediately before detection.

A second technique for detecting short-lived free radicals is called spin-trapping and is based on stabilizing the radicals themselves. A spin trap, usually a nitrone or nitroso compound, reacts with a free radical to form a stable nitroxide free radical which may be detected and studied by an EPR spectrometer. As shown in Fig. 6, the nitroxide gives an EPR signal which has characteristics unique to the radical added to it (i.e., the radical adduct).

Continuous flow and spin-trapping have provided great advantages in studying reactions involved in the autoxidation reactions of unsaturated fatty acids. By varying flow rates and using three different spin traps, alkyl radicals from the initiation step and alkoxy and peroxy radicals from the propagation stage of the free radical autoxidation chain reaction have been distinguished.

Differences in oxidation reactions induced in pure lipids by a variety of initiators — metals, ozone, superoxide anion, ultraviolet light, electrolysis, etc., are being investigated. Extension of these studies from simple to more complex reaction mixtures will eventually provide information that will help define the role of oxidizing lipids, and the free radicals thereby produced, in cytotoxic processes.

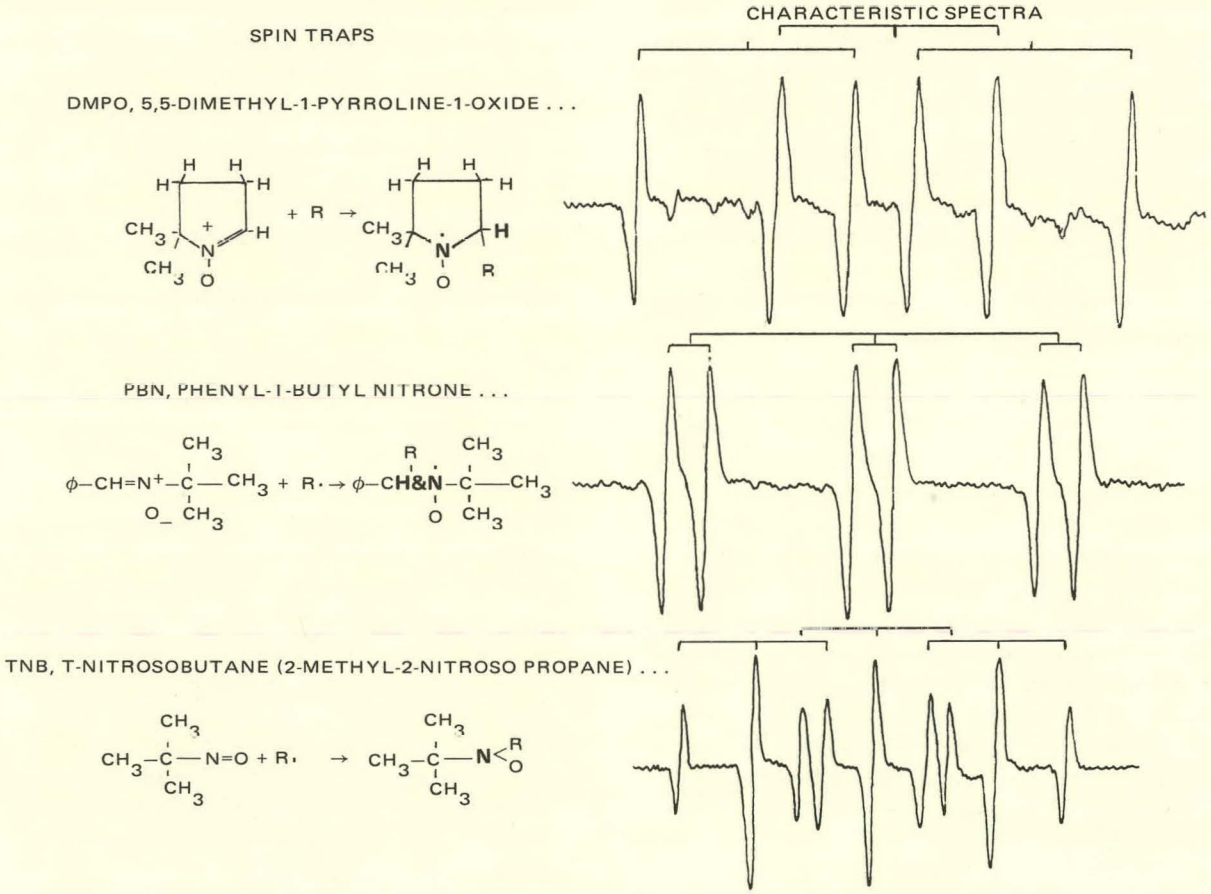

Figure 6. Spin traps commonly used in biological systems: structures and characteristic alkyl radical adduct spectra. Primary triplet splittings arise from the nitroxide nitrogen; secondary splittings result from adduct influences on β-hydrogens of nitrone traps (heavy type) and from the hydrogens of nitroso spin adducts (R). Spectra are not on identical scales.

Reactions and Cytotoxic Activity of Phagocytic Cells

Macrophages and polymorphonuclear leukocytes, in the process of engulfing and digesting bacterial cells or particulate matter, are thought to elaborate superoxide anion and hydroxyl radical, ·OH, two potent cytotoxic compounds. These cells at the same time emit chemical light, called chemiluminescence, which may be detected and characterized using a photon counter. Chemiluminescent measurements of model chemical reactions and of phagocytic cells activated by a variety of agents are being coordinated with spin-trapping of the radical species produced at the same time to understand: a) what kinds of agents (physical or chemical) can stimulate these cells; b) what reactions are involved in the activation, phagocytic, and digestion processes; and c) which free radicals or other cytotoxic compounds are produced by the cells under various conditions mimicking *in vivo* exposure situations. Extension of these *in vitro* studies to *in vivo* activation and reactions of phagocytic cells in sheep will provide the basis for assessing the contribution of these cells to lung damage following exposure to oxidative air pollutants.

Extrapulmonary Effects of Oxidant Gases

Whether ozone and other oxidant gases affect tissues other than lung remains an important unanswered question. In man, biochemical changes in red blood cells have been detected after short exposures to low levels of ozone, but these effects have not been observed in small laboratory animals. New animal studies in the Medical Department are thus being focused on sheep, in which the lung structure more closely resembles that of man. An additional advantage accrues from the size of these animals, which allows coordinated measurements of pulmonary function, immunological responses, cytogenetic effects, and various biochemical changes.

INTERACTION OF CARCINOGENIC AGENTS ON THE INDUCTION OF MAMMARY TUMORS IN RATS

Both certain chemicals and ionizing radiation are known to be carcinogenic agents for the mammary gland of rats. The mammary gland tumors found in rats after either chemical carcinogen treatment or after irradiation appear to be of similar histopathological types and, depending upon the dose of the carcinogenic agents, appear to show similar latent periods between application of the carcinogens and the appearance of the mammary tumors. In the few instances where a chemical carcinogen and ionizing radiation have been studied in combination, the two agents appear to show an additive effect on rat mammary carcinogenesis. These results suggest that at least some chemical carcinogens and physical carcinogens may be, in a general sense, interchangeable in regard to their carcinogenic effect on rat mammary gland tissue. It has been demonstrated previously at Brookhaven and elsewhere that x-radiation and DES (diethylstilbestrol, a crystalline, synthetic estrogen) act synergistically on mammary tumor formation in female rats of the ACI strain. It thus seemed of interest to replace x radiation with a chemical carcinogen, and see if the synergistic interaction with DES would be maintained. Accordingly, a well-studied chemical carcinogen for the rat mammary gland, DMBA (7, 12-dimethylbenz (a)anthracene) was administered to female rats of the ACI strain, with and without DES administration, using the same DES treatment that had shown a synergistic interaction with x-rays.

All rats were followed for 266 days, when they were killed and examined for mammary tumors. Of the 33 rats given DMBA only, 9 developed a total of 10 mammary tumors. Of the 29 rats given DES only, 10 rats developed 47 mammary tumors. Of the 24 rats given the combination of both DMBA and DES, 20 rats developed 126 mammary tumors, while no mammary tumors were found in 20 non-treated, control rats. A statistical analysis disclosed that the interaction between DES and DMBA was synergistic in regard to both the proportion of rats that developed one or more mammary tumors and the proportion of rats that developed two or more tumors. Thus the interaction of DES and DMBA, as observed in this study, and the interaction of DES and x rays, observed previously, appears to be approximately the same. It was concluded that, in this animal model system of mammary tumor induction, the physical car-

cinogenic agent, x irradiation, and the chemical carcinogenic agent, DMBA, can be thought of as being interchangeable.

INTERACTION BETWEEN ENVIRONMENTAL POLLUTANTS AND ONCOGENIC VIRUSES IN CARCINOGENESIS

The concept of environmental causation of human cancer has been emphasized by many scientists: it has been estimated that over 90% of human cancers are caused by agents in the environment. However, cancer in man usually has not unifactorial but multifactorial causes. Therefore, additive mechanisms, syncarcinogenic activity, and enhancing and modifying factors influencing the carcinogenic processes (namely cocarcinogenesis) seem to be the central problems of environmental carcinogenesis. Cocarcinogenic action refers to any external factor which increases tumor induction when administered together with a sub-optimal dose of carcinogen.

The objectives of this research are to develop reliable short-term methods for detection of potential carcinogens and to evaluate the role of chemical carcinogens and mutagens in promoting viral oncogenesis.

In order to assay potential carcinogens and mutagens, an *in vitro* transformation system was chosen in which simian adenovirus 7 (SA7) is used as a tool and indicator to study the capacity of chemicals to enhance SA7 transformation of primary hamster embryo cells (HEC) and lung cells. Forty-seven compounds (salts of 19 different metals) were examined for their ability to enhance the frequency of SA7 transformation. The metal salts showing highest activity, based upon the concentration required to enhance viral transformation, were those of arsenic, cadmium, chromium, silver, mercury, and vanadium (concentrations less than 0.06 mM). A second group of metal salts, including those of nickel, zinc, cobalt, titanium, lead and copper, increased the frequency of viral transformation when HEC were treated with concentrations in the range of 0.06-0.5 mM. The third group, consisting of beryllium, iron, manganese, and lithium, had the lowest activity, since concentrations of 1.43 mM or greater were required for transformation. The results obtained with metal salts used in the viral enhancement assays were in agreement with the reports of other investigators. When hamster embryo cells were treated with aromatic and aliphatic compounds the frequency of viral transformation of these cells was increased two, three, and four-fold.

Studies in our laboratory also demonstrated that treatment with carcinogenic polycyclic hydrocarbons increased the susceptibility of hamster cells to transformation by SA7. However, treatment with the noncarcinogenic polycyclic hydrocarbons phenanthrene and pyrene was ineffective.

When hamster lung cells were pretreated with $NiSO_4$ and $BeSO_4$ (metal salts reported to have caused lung carcinomas in animals), the frequency of viral transformation of these cells was increased. The enhancement of SA7 transformation in lung cells treated with $NiSO_4$, $BeSO_4$, $ZnCrO_4$, and $NaAsO_2$ was greater than that observed in hamster embryo cells.

Enhancement of viral transformation by chemicals may result from damage to cell DNA, thereby creating additional sites for attachment of viral DNA. Evidence for such damage was found by examining the changes in the sedimentation profile of [^{3}H] thymidine-labeled cell DNA following chemical treatment. One group of metal salts was found to be capable of inducing DNA breaks in hamster embryo cells while a second group was found to have no effect. Since both groups of metal salts caused significant enhancement of viral transformation, the results suggest the possibility of more than one mechanism of viral activation by chemicals.

This assay offers a quantitative, reliable, and reproducible system. Moreover, the use of primary mammalian cells makes the test sensitive to a wide range of carcinogens and mutagens, including metal salts and carcinogenic hormones that are detected poorly or not at all in microbial systems. The test is easy to read, can be obtained within a reasonably short time, and gives quantitative information, necessary in screening for potential environmental mutagenic or oncogenic agents. The presence of virus in this screening test increases the sensitivity of the test and makes possible the study of mechanisms of chemical and viral interaction in carcinogenesis.

NUCLEAR MEDICINE

RADIONUCLIDE RESEARCH PROGRAM

The major objectives of this program, like those of the more comprehensive Nuclear Medicine Program of which it is an integral part, are to perform research leading to the development and applications of new and improved radiopharmaceuticals for diagnostic and therapeutic use. Past and continuing achievement of these goals is evidenced by the development of technetium 99*m*, technetium-99*m*-radiopharmaceuticals, thallium 201, various other nuclides, and the present increasing demand for xenon 127. Currently, over 80% of all diagnostic nuclear medicine procedures involve one of these radionuclides. The combination of wide scope, variety and uniqueness of facilities available at BNL, and the expertise of the scientific staff make this a most unusual and rare program. Noteworthy facilities include the BLIP (Brookhaven Linac Isotope Producer), high-level radiation processing facilities, and the excellent animal-test and clinical facilities.

The ability of BLIP to have a significant impact on the medical community was demonstrated by the production and distribution of more than 50 curies of xenon 127 during the year to more than 35 institutions and to the BNL pulmonary program. In addition, other isotopes were produced and distributed to research collaborators, including iodine 123, iron 52, ruthenium 97, germanium 68, and tungsten 178. A process using manganese targets was developed for BLIP production of iron 52 containing significantly less iron 55 contamination. A manganese 52*m* generator which uses iron 52 as a parent was developed. Manganese 52 *m*, a 21-minute positron emitter, has shown considerable promise for use in positron emission tomography for evaluating regional myocardial perfusion. In a collaborative program with Columbia College of Physicians and Surgeons, palladium-109-labeled hematoporphyrin is being studied for the temporary suppression of the body's immune response following organ transplants.

The major thrust of the program during the past year was toward the development of new radiopharmaceuticals labeled with ruthenium 97. Ruthenium 97 (2.9-day half life) has excellent physical properties and ruthenium is reactive chemically, offering the potential for the synthesis of a variety of compounds and complexes. A number of ruthenium-labeled com-

Table I

A Comparison of the *In vivo* Distribution of Ruthenium-labeled Transferrin[a] and Gallium-67 Citrate [b] in Tumor-bearing Mice[c]

Compound	Time post-injection, hours	Tissue Uptake[d]					
		Tumor	Blood	Muscle	Liver	Kidneys	TCI[e]
Ruthenium-103-transferrin	24	12.8	12.9	1.6	8.9	8.4	2.7
	48	13.3	4.6	1.3	7.5	7.2	3.8
	72	12.4	2.5	1.0	6.1	6.1	4.5
Gallium-67-citrate	24	7.1	1.8	0.5	9.3	9.2	1.8
	48	5.1	0.5	0.5	9.5	8.0	1.5
	72	4.5	0.4	0.5	8.4	7.5	1.6

[a]The transferrin was initially labeled with ruthenium 103 for convenience. Ruthenium-97-labeled transferrin is expected to show an identical bio-distribution.

[b]Gallium-67 citrate is the most widely used tumor localizing agent at the present time.

[c]Balb/c mice with a transplantable EMT-6 sarcoma.

[d]Data are expressed as the percent of injected dose per gram of tissue at indicated time periods after intravenous injection.

[e]The tumor concentration index (TCI) provides a measure of the tumor uptake compared to the mean body concentration of the radiotracer, and is expressed as the ratio of percent dose per gram in tumor to percent dose per gram remaining in the whole body at various intervals after injection.

pounds, including ruthenium (III and IV) chloride and complexes of ruthenium (II, III, and IV) with O,O; O,N; and N,N donor ligands, were successfully prepared, characterized, and evaluated in animal systems. Several ruthenium-labeled compounds continue to show promise for a number of applications including tumor localization, bone and myocardial infarct uptake, hepatobiliary function determination, cisternography, cell labeling, and lymphoscintigraphy with colloidal material. Efforts were directed primarily to applications in which biological processes require a radionuclide with a half-life longer than that of 6-hour technetium 99*m*. Evaluation of ruthenium-labeled transferrin in tumor-bearing animals showed the tumor uptake of this agent to be twice as high as that of the most commonly used compound, gallium 67 citrate (Table I). Studies on the uptake mechanisms indicate a transferrin-mediated transport of the tracer into the tumor cells. These studies are continuing in collaboration with the VA Hospital, Seattle, and the Memorial-Sloan Kettering Institute, New York. Studies on the chemistry of various potential ruthenium radiopharmaceutical systems *in vitro* and *in vivo* continue to provide useful mechanistic information which will no doubt aid in the design of superior new agents.

PROMPT GAMMA NEUTRON ACTIVATION ANALYSIS (PGNAA)

Cadmium

A study was completed on *in vivo* measurement of cadmium in smokers and non-smokers. Absolute amounts of cadmium (mg) in the left kidney and concentrations of cadmium (μg/g) in the liver were measured *in vivo* in 20 healthy adult male volunteers. Organ cadmium levels of smokers were significantly elevated above those of non-smokers. No relationship was evident between body stores of cadmium (liver and kidney) and cadmium or β_2-microglobulin in urine or blood. The average total body burden of cadmium in man at age 50 is estimated to be 19.3 mg for non-smokers and 35.5 mg for smokers (38.7 pack-year smoking history). Biological half-time for the whole body was, on average, 15.7 years (10 to 33 year range). Dietary absorption was 2.7 μg/d. Cigarette smoking resulted in the absorption of 1.9 μg per pack.

The neutron activation facility used for the prompt gamma analysis of cadmium was mounted on a 10.4m mobile trailer unit (Fig. 7). With partial support by the International Lead-Zinc Research Organization, it was used to monitor levels of Cd in 84 industrial workers in a smelter in Denver, Colorado and 10 control subjects. Dose-effect relationships between kidney cadmium burden and kidney damage as manifested by high urinary levels of β_2-microglobulin are currently being evaluated in these workers. It is anticipated that these critically important data on the industrially-exposed workers will provide a basis for determining critical concentrations with respect to biological effect. They will also be

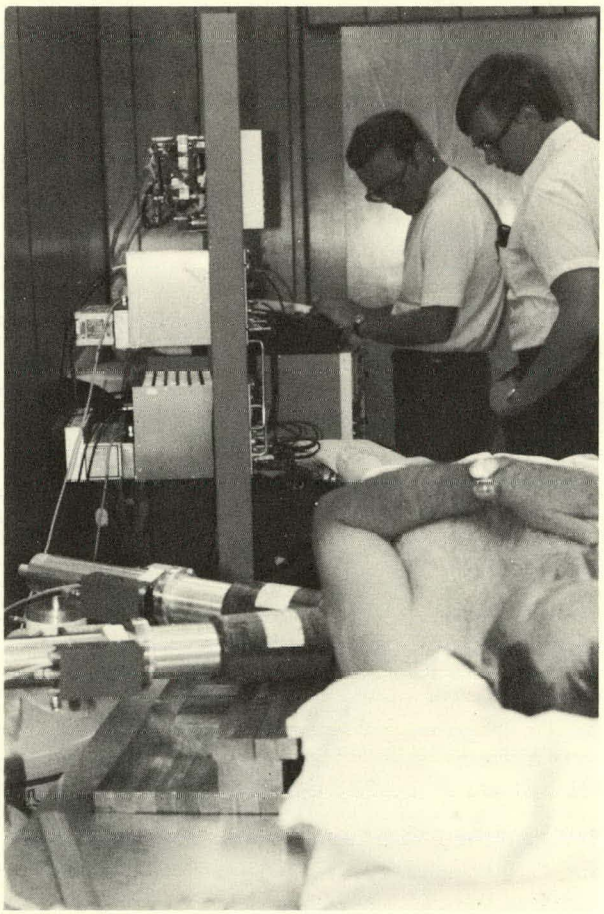

Figure 7. The inside of the BNL trailer containing a neutron activation facility is shown. A smelting plant worker is having the cadmium concentration in his kidney measured. The trailer was transported to Denver in August 1979 to conduct a study on the possible hazards from Cd deposited in the body.

valuable for setting or revising permissible levels for industrial and environmental Cd pollution.

Nitrogen

An NIH-NCI contract supports a study in collaboration with the Long Island Jewish Hillside Medical Center on *in vivo* quantification of body nitrogen in normal subjects and cancer patients, and changes in body composition in cancer patients as related to diet. The technique of prompt-gamma neutron activation analysis (PGNAA) for total body nitrogen (TBN) has been validated and the calibration completed. To date, TBN has been measured in 135 normal male subjects and 60 cancer patients. On the completion of this study, a mathematical model for the determination of the normal levels of nitrogen will be developed as a function of age, sex, and the size of the subject. The deficit in TBN will be evaluated in cancer patients.

A new compartmental analysis technique employing both TBN and total body potassium (TBK) data has been employed. This analysis provides new insights into changes in body composition in normal subjects and in cancer patients, particularly in response to altered nutritional status. From the differential concentration of N and K in muscle and non-muscle lean tissue, it is now possible to devise a compartmental model of body composition. Model equations have been formulated to determine both the mass and the protein content of muscle and non-muscle lean tissue, and from the K measurement alone, a third compartment, adipose tissue, can be determined. In addition, the protein content of each of the compartments can be determined. In cancer patients, the assessment of protein status and the changes with nutritional status are of primary importance. The elucidation of these relationships can serve to improve the clinical management of cancer patients.

NUCLEAR RESONANCE SCATTERING

A technique for the measurement of body iron utilizing nuclear resonance scattering of gamma rays has been developed and validated. From this prototype study, a full scale facility is being developed for clinical application. Photons (847 keV) emitted from a gaseous $^{56}MnCl_2$ source (prepared in the BNL Medical Reactor) are scattered resonantly from ^{56}Fe present in the liver and heart. The spatial uniformity of activation, the sensitivity of the detection system, and the limits of detection have been investigated. Measurements were made on a liver phantom. The resonance scattering technique permits detection of normal levels of Fe in the liver with a radiation dose of 2 Rem. A research grant has been obtained from NIH for support of this research and its clinical application (thalassemia).

DELAYED GAMMA NEUTRON ACTIVATION

Physical Therapy

Studies of the effects of physical therapy on the skeletal mass of older human subjects are in progress with the support of an NIH Aging Institute grant. These studies include measurement of the normal changes in skeletal mass with age. The measurement of total body calcium levels in 135 normal subjects, 20-90 years of age, was completed this year.

Combination Therapy in Osteoporosis

The study of the effects of combination therapy which simultaneously stimulates bone formation and inhibits bone resorption in osteoporotic patients was continued. To date, 30 patients were studied before and after one to two years of growth hormone-calcitonin therapy. The results continue to reinforce the finding of a positive Ca balance previously reported, suggesting an increased skeletal mass after combination therapy.

NEW NUCLEAR TECHNIQUES FOR APPLICATION IN ENVIRONMENTAL HEALTH STUDIES

Silicon Studies

Feasibility studies were initiated for the *in vivo* measurement of silicon and beryllium by nuclear techniques. Silicon, in the form of free crystalline silica, and beryllium, as BeO dust, are potentially hazardous lung contaminants. Silicosis is a chronic fibrosing of the lungs that may occur in workers in a variety of industries including mining, quarrying, and stone cutting. The lungs of individuals with silicosis may contain up to 10 g of Si as free silica (compared with a normal level of about 0.1 g). With such large amounts of the material, a non-invasive tech-

nique for Si analysis is feasible both for screening exposed workers and also as a research tool for the investigation of the dose-response relationship of the element.

One of the measurements developed utilizes the inelastic neutron scattering reaction of $^{28}Si(n, n'\gamma)^{28}Si$ via the prompt 1.78 MeV emission from the first excited level. This level is also populated by the β-decay of ^{28}Al, produced by an n, γ reaction on ^{27}Al and an n, α reaction on ^{31}P. However, for neutron energies below about 4 MeV, most of the 1.78 MeV photons from an *in vivo* activation would be expected to arise from the n, n′ reaction in Si. An experiment using 13.5 mCi ^{252}Cf (5.7×10^7 n/sec) and two Ge(Li) detectors, each of 24% relative efficiency, yielded a sensitivity for Si of 130 cts/g/Rem in a phantom. This value represents a detection limit (2 SD of background) of about 6.5 g Si in the lung. Improvements may be made in detection efficiency and reduction of the background with the use of a pulsed neutron source and/or a Compton suppression system.

BORON THERMAL/EPITHERMAL NEUTRON CAPTURE THERAPY

Recently a grant has been received from the NIH to study a neutron radiotherapeutic procedure using the $^{10}B(n,\alpha)^7Li$ reaction. Given physiological uptake of boron in tumors, the neutron capture reaction provides potentially optimal condition for radiotherapy as the short range of the He and Li ions (~10μm in tissue) permits selective irradiation of cancer cells within the radiation field. Precise knowledge of tumor location and extent is not necessary, as the general area can be included in the neutron field. Further, the high linear energy transfer particles provide a low oxygen enhancement ratio, thus reducing the radio-resistance of hypoxic cells within the tumor volume.

Previous clinical trials at Brookhaven's Medical Research Reactor (MRR), and MIT/Massachusetts General Hospital in Boston were terminated in 1961. The consensus was that poor clinical results were a consequence of 1) poor tissue penetration provided by the thermal neutron beams used (half value layer $\simeq$ 1.8 cm in tissue), and 2) relatively high levels of boron in blood (equal to or greater than the concentration in tumor).

Since that time there have been a number of developments. Efforts were successful in the construction of an "epithermal" neutron beam at the MRR, with better tissue penetration. By filtering out incident thermal neutrons, those with a higher average energy (>0.4 eV) are allowed to moderate in tissue, thus producing peak thermal neutron flux densities at depths varying with the degree of filtration. Extensive dosimetric measurements demonstrate that the improved neutron distributions should make all parts of the body accessible to neutron capture therapy, thus obviating the previous problem of poor penetration.

In addition, new borated compounds have been developed. These include sodium mercaptoundecahydrododecaborate ($Na_2B_{12}H_{11}SH$) currently being used for clinical trials in Japan. Results there with a series of 35 brain tumor patients have been encouraging, with useful life being extended; longest survival to date has been 6.3+ years. Improved results are attributed to a better tumor-to-blood boron concentration ratio (avg. $\cong$ 1.8), and the use of significantly reduced thermal neutron fluences.

More recently chlorpromazine (CPZ), known to combine with pigment in melanoma, has been synthesized (in Japan) with ~ 25% by weight boron ($C_{17}H_{30}Cl_1S_1N_2B_{12}$) (Fig. 8). This compound is the one with which we are primarily concerned in the present NIH grant. CPZ is itself relatively nontoxic, and clears the blood rapidly. In the uveal tract and melanoma it has a retention half-life in the order of days, with pigmented/non-pigmented tissue ratios exceeding 10. Studies of melanin concentration in hu-

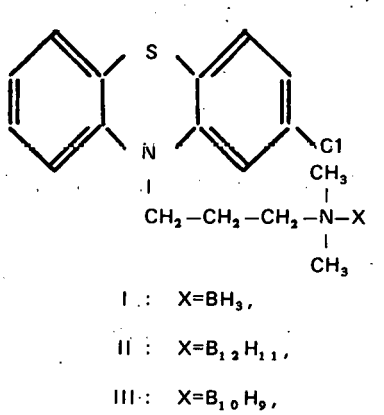

Figure 8. Borated analog of chlorpromazine.

man and animal tissues and of CPZ uptake in animal models (Greene melanoma in hamsters; Harding-Passey in BALB mice) indicate levels of CPZ in melanoma adequate for therapy. Work is in progress on anionic, neutral, and cationic borated CPZ analogs. Pilot studies are also underway to evaluate the possible efficacy of other polycyclic heteroaromatic compounds known to have tumor affinity. These would perhaps be applicable to many types of tumors. The anion borane $B_{12}H_{11}SH^{2-}$ itself (now in use for brain tumors in Japan) has been reported to show favorable differential and absolute concentration in spontaneous (extra-cranial) animal tumors.

Preliminary studies are underway to evaluate the therapeutic value of $B_{12}H_{11}SH^{2-}$ in an intracranial glioma, in conjunction with a group from NYU. This possibility is exciting as it enables one to take advantage of the physical exclusion from normal tissues provided by the blood-brain barrier. Additional studies are underway with other groups in an effort to utilize immunological mechanisms to facilitate boron transport to tumors.

REGULATORY MECHANISMS OF ERYTHROPOIETIN PRODUCTION

The objectives of this research are twofold: (1) to study the regulation of erythropoiesis, and (2) to investigate whether there are regulatory mechanisms of red cell production which are independent of or co-existent with erythropoietin (Ep), the putative erythropoietic hormone.

Animal Studies

These studies have been directed toward defining the mechanisms by which Ep levels are increased or suppressed in experimental animals. One of the models investigated during the past year had as it major objective the elucidation of the degree of hypoxemia required to initiate Ep production in rats. Rats were exposed to O_2 concentrations ranging from 5 to 9% O_2 for either 3 or 16 hours. The arterial pO_2 values ranged from 25 to 40 mmHg, Ep levels were not increased. There was a highly significant correlation between both the arterial pO_2 and O_2 saturation and the plasma Ep level in these severely hypoxemic rats.

These studies were extended to define the mechanism whereby hypercarbia suppresses Ep production in hypoxemic rats. The addition of 5% CO_2 to all inhaled gas mixtures was associated with a 10 mmHg increment in the pO_2 together with a marked reduction in plasma Ep levels. The results obtained demonstrated that the mechanism by which hypercarbia suppressed Ep levels in hypoxemic rats was directly correlated with increments in the pO_2 and/or O_2 saturation produced by hyperventilation.

We have also demonstrated that there was a 50% reduction in plasma Ep levels in mice hypertransfused with homologous washed red blood cells. A similar reduction in baseline plasma Ep levels was also measured in mice exposed to 100% O_2. In the former situation the most likely explanation for the observed reduction in plasma Ep levels was the increment in the number of red blood cells capable of transporting oxygen to the tissues and in the latter situation the amount of O_2 in solution in the hyperoxic mice probably provided a negative feedback signal to the kidney and/or extra renal sites of Ep production. An alternative explanation might be that circulating inhibitors to Ep were released with both hypertransfusion and hyperoxia.

Human Studies

It is clear from our animal studies that Ep is a hormone which regulates the production of red blood cells in extreme situations, e.g., severe hypoxia, massive hemorrhage, etc. We have in our human studies attempted to determine if this hormone is the sole regulator of red cell production in man. In preliminary studies our data indicate that there is most likely another mechanism(s) regulating the normal daily replacement of red cells in man. We have subjected normal volunteers to graded amounts of daily blood loss and have failed to demonstrate any increases in their Ep levels over the course of a week. When subjected to a single phlebotomy of 450 ml of blood there is a rapid doubling in Ep levels in normal man.

In another study subjects with mild to moderate chronic lung disease were studied to determine the relationship between arterial pO_2, O_2 saturation, red cell mass, and Ep levels. The subjects investigated were hematologically normal and free of infection at the time of our studies. There was no correlation between the

arterial pO_2, O_2 saturation, or red cell mass and the amount of Ep measured. Six of the subjects studied had elevated Ep levels with normal red cell masses. We have not excluded the possibility that those subjects with elevated Ep levels will eventually develop polycythemia, one of the complications of chronic lung disease.

These experimental data provide us with strong indirect evidence that the hormone Ep is not the sole regulator of red cell production in man. Further investigative efforts will be directed toward defining the regulation of red cell production in normal man.

STUDIES ON HYPERTENSION

Hypertension is a multifactorial polygenic disorder and there is a need to identify the genetic and environmental factors involved in its etiology and their interactions. Hypertension is one of the major risk factors in determining the morbidity and mortality of coronary artery disease.

Selective breeding has produced two lines of rats with opposite and predictable blood pressure response to high salt intake; Dahl salt-sensitive "S" rats, which develop severe hypertension on high salt diet but remain normotensive on low salt diet, and Dahl salt-resistant "R" rats which are normotensive on either. Regarding the importance of these rats, it should be stressed that human essential hypertension definitely has a "salt angle" to it. In our clinical studies, emphasis is placed on the role of salt in essential hypertension and the association of hypertension with coronary artery disease. We know that a life-long low sodium intake will completely prevent essential hypertension and a low sodium diet will reduce the level of blood pressure in patients with hypertension.

Since human essential hypertension has this salt dependent feature, these two Dahl rats serve as an excellent experimental model for the study of human essential hypertension.

Catecholamine, Salt, and Hypertension

We have reported that the "S" rats, following peripheral sympathectomy, did not develop hypertension on high salt diet, suggesting that the peripheral sympathetic nervous system plays an important role in the development of salt hypertension.

In order to pursue the role of catecholamine in the development of salt hypertension in "S" rats, norepinephrine and epinephrine were measured in the brain stem, hypothalamus, and adrenal gland. "S" rats had significantly higher hypothalamus and brain stem norepinephrine than did "R" rats. Furthermore, norepinephrine levels increased in conjunction with salt intake and hypertension in "S" rats, whereas a decrease in norepinephrine levels was observed in "R" rats on high salt. Adrenal norepinephrine levels showed a decrease in "S" rats but an increase in "R" rats on the high salt diet.

These results indicate that there is a link between catecholamine and salt in the development of hypertension.

Inbreeding and Hypertension

To better control and understand the genetic factors involved in hypertension, we are inbreeding the two lines of Dahl rats. Brother by sister matings are used within each line to produce animals that are progressively more similar to each other in genetic composition. Thus within each inbred strain, each rat will be a genetic replicate of the other, with the exception of the sex chromosomes. Currently in the ninth and tenth generations, the rats will become inbred after a minimum of 20 generations. The resulting inbred animals will allow the distribution of breeder-pairs of these rats to the biomedical community and enable more accurate investigations of the importance of genetic and environmental factors in the development of hypertension.

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Environmental Health Sciences Program
R.T. Drew, Coordinator

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Inhalation Toxicology and the Physiology, Biochemistry, and Morphology of Human Pulmonary Disease — **R.T. Drew,** M. Kuschner, J.C. Acevedo, D.M. Bernstein, D.L. Costa, G. Schidlovsky, D.N. Slatkin, R.S. Kutzman, J.D. Glass.

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The Effects of Toxic Agents on Cells in Culture — **J.C. Acevedo.**

Inhalation Toxicity of Glass Fibers (TIMA) — **R.T. Drew.**

Respiratory Pathology Training Grant (NIEHS) — **R.T. Drew.**

Inbreeding of Dahl S and R Rats (NHLBDI) — **J. Iwai,** S.B. Haber.

Nuclear Medicine and Medical Physics
S.H. Cohn, Coordinator

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Melanoma Detection (NCI) — **H.L. Atkins.**

Program in Support of Nuclear Medicine (NINCDS) — **H.L. Atkins.**

Boron Epithermal-Neutron Capture Therapy (NCI) — **R.G. Fairchild,** S.J. Hannon.

Gerontological Changes in Skeletal Mass (NIA) — **S.H. Cohn.**

Diet, Nutrition, and Cancer (NCI) — **S.H. Cohn,** A.N. Vaswani.

In vivo Measurement of Body Iron by Nuclear Resonance (NIH) — **S.H. Cohn,** L. Wielopolski

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Interaction Between Energy-Related Pollutants and Oncogenic Viruses in Carcinogenesis — **M.T. Pavlova.**

Evaluation of Hazards of Byproducts from Nuclear and Nonnuclear Energy Generation — **A.L. Carsten,** S.L. Commerford, D.N. Slatkin.

Human Chromosomal Aberration Production by Energy-Related Agents — **M.A. Bender,** R.R. Tice, R. Kale.

Teratogenesis — **D.W. Slater.**

Hormones, Neutron Irradiation and Mammary Gland Carcinogenesis (NCI) — **C.J. Shellabarger.**

NCI Training Grant — **C.J. Shellabarger** (Medical Department Coordinator).

Host Defense Sciences Program
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Effect of Chemicals and Radiation on Control of Hemopoiesis — **E.P. Cronkite,** H. Burlington, A.L. Carsten, A.D. Chanana, S.L. Commerford, S. Harigaya, T. Inoue, M. Jamuar, D.D. Joel, J.E.T. Kelley, W.L. Kennedy, M.E. Miller, G. Moccia.

Penetration Through the Gut and Bioeffects of Particulates from Nonnuclear Energy Production — **D.D. Joel,** M.E. LeFevre.

Early and Late Effects of Energy-Related Pollutants on Immunologic Systems — **R.D. Stoner.**

Hemopoietic Regulators (NHLBDI) — **E.P. Cronkite.**

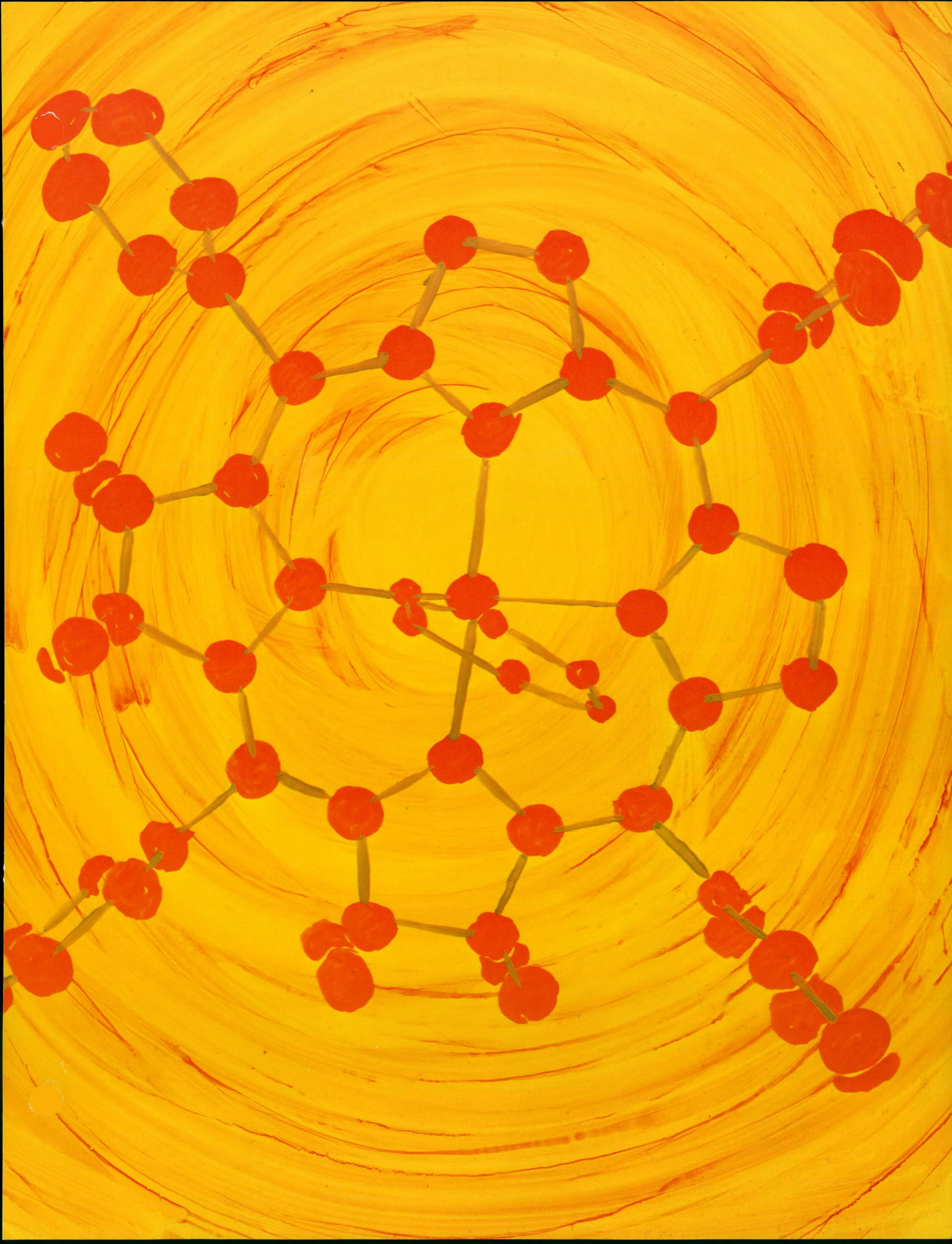
Neutrophilic Granulocytopoiesis (NCI)—**E.P. Cronkite.**

Regulatory Mechanisms of Erythropoietin Production (NHLBDI) — **M.E. Miller.**

Applied Energy Science

Department of Energy and Environment

Department of Nuclear Energy



Department of Energy and Environment

INTRODUCTION

The objectives of the Department of Energy and Environment (DEE) are to generate a base of scientific, economic, and technical data on selected energy technologies and on the effects of energy-related activities on the environment. The research and development in the fundamental and applied program is performed in four main areas (1) Energy Sciences, (2) Environmental Sciences, (3) Energy Technology, and (4) The National Center for Analysis of Energy Systems.

* * * * * * *

Energy Sciences

CHEMISTRY, MATERIALS, AND PROCESS SCIENCES PROGRAMS

In the area of Energy Sciences work is carried out in the chemical, materials, and process sciences. The chemistry studies are concerned with basic and applied research on synthetic photosynthetic compounds, combustion of fuels, mechanisms involved in coal liquefaction, analytical methods, studies of membranes, metal hydrides, and other related studies.

Research on materials is focused on the study of materials of importance in the production, transmission, and storage of energy. Included are studies of superconducting materials, hydrogen in metals, materials for solar applications, plastic materials for dielectrics in power transmission cables, electrode materials, and behavior of materials under stress and in corrosive media.

The work in process sciences applies chemical and physical methods and techniques to the development of efficient and environmentally acceptable processes for the conversion of natural resources to the production of fuel, power, and materials of construction to meet energy requirements in the U.S.

Recent advances during 1979 in the Energy Sciences are reported below.

CHEMICAL SCIENCES DIVISION PORPHYRIN CHEMISTRY PROGRAM

Structural Studies

Bacteriochlorophylls are key components in the harvesting and the conversion of light into chemical energy in bacterial photosynthesis. The first determination of a structure of a bacteriochlorophyll derivative, methylbacteriopheophorbide, has been accomplished by x-ray diffraction, Fig. 1. (The compound is a primary electron acceptor in the light-induced genesis of oxidants and reductants.[1]) These x-ray data provide the stereochemical and bonding information required for structure-function and structure-reactivity correlations in order to characterize the molecules *in vivo* and in artificial photosynthetic systems.

Reaction Modeling

We have recently proposed[2] a mechanism for the transduction of light into chemical species in photosystem II of plant photosynthesis (oxygen evolution) that invokes the picosecond generation of a monomeric chlorophyll cation (complexed to a protein residue) and of an anion of pheophytin, a demetallated chlorophyll. To model this reaction, a cofacial diporphyrin link-

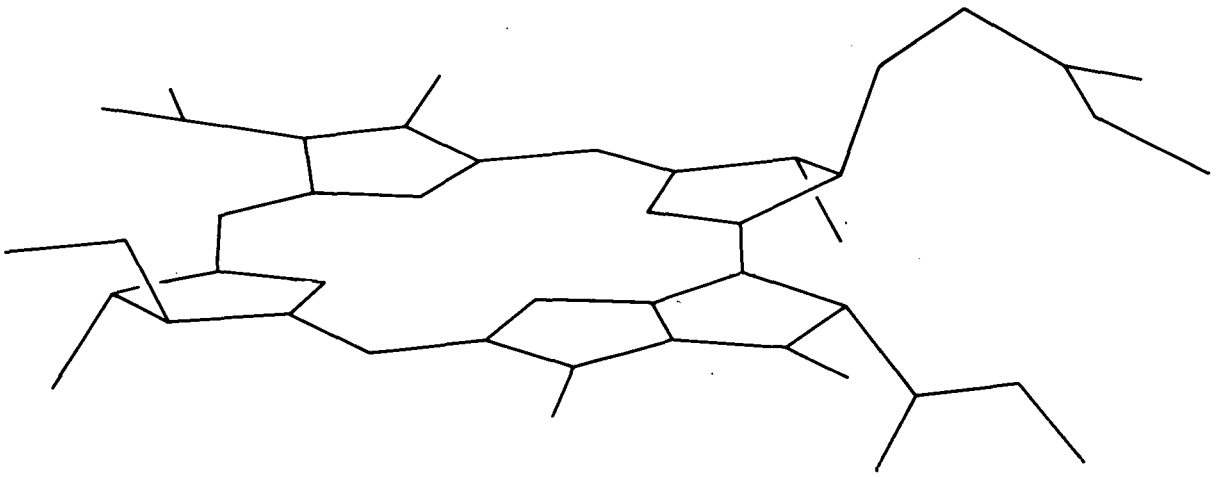


Figure 1. A perspective drawing of the structure of methylbacteriopheophorbide. Bacteriopheophytin, the compound found in photosynthetic bacteria, has a long chain of 20 carbons ($C_{20}H_{30}$) as the esterifying group. Bacteriopheophytin, *in vivo*, accepts an electron from photoexcited bacteriochlorophylls in less than 3 picoseconds and transfers it to the next electron acceptor in ~ 150 psec thereby preventing back recombination of the oxidants and reductants generated by the incident light.

ing a magnesium porphyrin to a demetallated one, about 4 angstroms apart, was synthesized (Fig. 2). When the diporphyrin shown was excited with 7 picosecond light flashes, the resultant optical changes indicated a charge separation into cations and anions within the lifetime of the flash, and the radical pair decayed back to the ground state in 620 (±20) psec.[3] This charge separation and its kinetics correspond well to the primary light reaction of photosynthetic systems. Synthetic manipulation of donor to accept distances, orientation, and redox characteristics has thus led to an *artificial* system which closely mimics the kinetics and energetics of photosynthetic organisms.

Nitrogen Assimilation

The assimilation of nitrite is an important bioenergetic process mediated by nitrite reductase. This enzyme contains siroheme, an iron isobacteriochlorin prosthetic group, which funnels 6 electrons into the substrate to generate ammonia: ($NO_2^- + 8H^+ + 6e_{siroheme} NH_4^+ + 2H_2O$). This reaction is light-driven in green plants; electrons photoejected from chlorophyll eventually reduce the siroheme. As part of a program to develop a synthetic system to generate ammonia photolytically, a series of isobacteriochlorins, which closely resemble siroheme structurally and spectrally, was synthesized and their optical, redox, and magnetic properties were characterized. A salient feature of the iso-

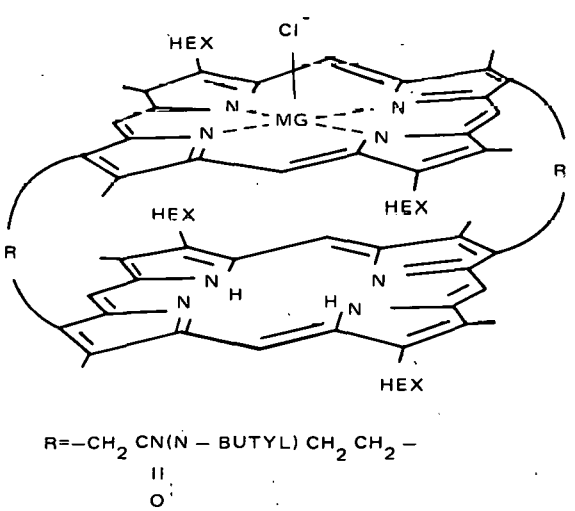


Figure 2. Drawing of a cofacial porphyrin in which one porphyrin is metal-free and the other contains a magnesium ion complexed by chloride. The porphyrins are ~ 4 Å apart. The compound is used to mimic the magnesium- and metal-free chlorophylls believed to effect the conversion of light into chemical species in the array of molecules which evolve oxygen in green plant photosynthesis.

bacteriochlorin framework is its ease of oxidation compared to porphyrins or chlorins. A striking example of this facile loss of electrons from the isobacteriochlorin macrocycle is found in a pyridine-carbon monoxide complex of an Fe_{II} isobacteriochlorin which, on oxidation, yields an Fe_{II} isobacteriochlorin radical and not the expected Fe_{III} heme.[4] These results suggest therefore that the biological generation of ammonia by nitrite reductase may occur via such radicals.

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COMPOUND SEMICONDUCTORS IN THE LIQUID AND SOLID STATE

High temperature electrochemical techniques have been used to study the electronic properties of compound semiconductors in both the liquid and solid state. Using a technique called coulometric titration[1-3], the range of stoichiometry of the compound $Li_{3+\delta}Sb$ was studied and results showed that δ varies between +.004 and −.004. The electrical conductivity was also determined as a function of Li content of the compound. Results are shown in Fig. 3 and it can be seen that the conductivity changes by over four orders of magnitude with very small variations in the Li content.

Analysis of thermodynamic and conductivity data yield the mobilities and concentration of electrons and electron holes as a function of δ as well as the effective masses of the charge carriers and the band gap of the compound semiconductor.

Experiments were also performed which show that Na_3Bi is a liquid semiconductor at 860°C.

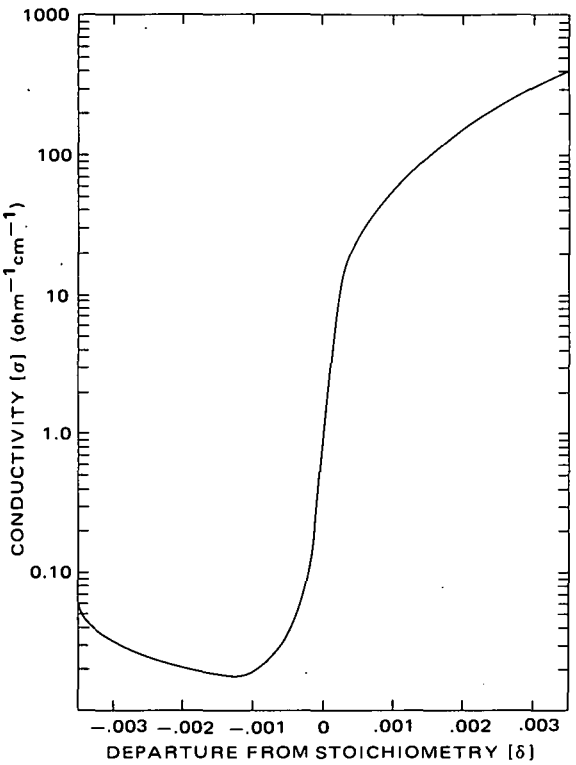

Figure 3. The electrical conductivity of $Li_{3+\delta}Sb$ as a function of departure from exact stoichiometry.

The electrical conductivity and temperature coefficient of conductivity were measured as well as the mobility and concentration of electrons and electron holes. Very little information is generally available for these interesting disordered semiconducting fluids and new techniques developed here are proving fruitful in obtaining new data.

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CYCLIC SEPARATIONS PROCESS RESEARCH

This program is concerned with the study of a class of chromatographic separation processes that have potential for large scale application in the energy technology field. The processes involve contact of a fluid mixture with a sorbing solid, cyclic variation of column pressure or temperature, and synchronous variation of fluid flow direction. These processes have the advantages that they render chromatographic processes continuous and they require no regenerant. The objectives of the research program are to obtain an understanding of the basis of operation of these so-called "cyclic separation processes" and to apply them to separation problems in energy technology.

Recent work has been focused on the separation of a gaseous mixture of hydrogen isotopes by contact with vanadium hydride. The latter substance exhibits an equilibrium isotope effect such that a heavy isotope is taken up preferentially from a mixture with a light isotope.

During the past year experiments have been conducted on the separation performance of two-column pressure or temperature cycling processes with a feed stream of hydrogen containing a trace of tritium (Fig. 4). The enrichment of tritium in one of the product streams and its removal from the other was found to be controlled not only by the known equilibrium isotope effect but also by a kinetic isotope effect in the rate of hydrogen absorption. The latter effect leads to slow uptake of tritium relative to hydrogen and is thus opposite to the action of the equilibrium effect. Work is in progress on processes that take particular advantage of one effect or the other.

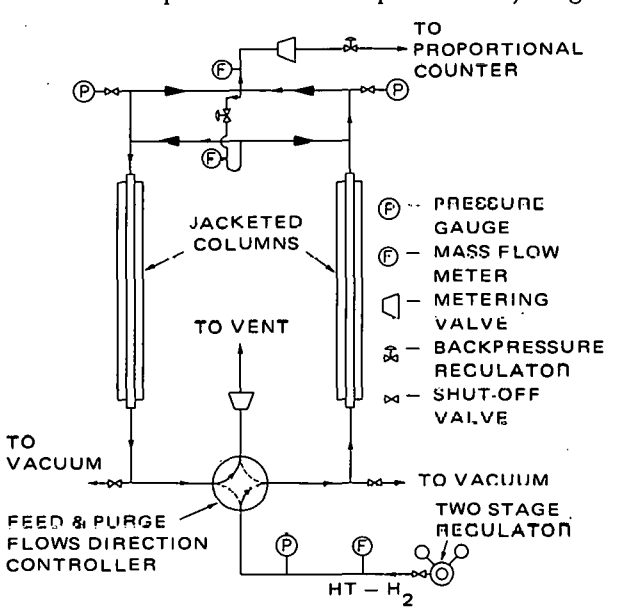

Figure 4. Schematic diagram of apparatus for the study of cyclic separation processes. Feed is directed to one column at high pressure or low temperature. A portion of the column effluent is taken off as product while the remainder is supplied to the second column as low pressure or high temperature purge. Feed introduction is changed from one column to the other periodically.

METALLURGY AND MATERIALS SCIENCE DIVISION METAL-HYDROGEN SYSTEMS

Hydrogen Uptake by Metals

Metal hydrides show great promise as media for energy storage. For some time, scientists at Brookhaven National Laboratory have been active in the search for materials which are best suited for hydrogen storage. Some of the factors which govern the usefulness of such materials are the stability of the hydride, and the capacity of the hydride, as well as the kinetics of the system, i.e., the rate at which hydrogen is absorbed and desorbed by the metal. If the metal is in the form of very small particles or if the diffusion of hydrogen in the material is very rapid, then the rate determining steps in the kinetics may be those involved in the surface itself; the transfer of hydrogen from the gas phase through the surface into the metal. Significant progress was made this year in understanding this process in some transition metals such as niobium (Nb) and tantalum (Ta) which serve as model substances. The experimental work led to a theoretical model for the absorption and desorption kinetics of hydrogen by such metals. The kinetics are governed by the existence of a strongly bound chemisorbed hydrogen state at the surface, the energy of which is lower than that in the bulk. Based on this knowledge it could be predicted and was successfully demonstrated experimentally that, by modifying the surface, in particular by depositing a few monolayers of palladium (Pd) on the surface, the kinetics could be dramatically enhanced.[1] Indeed, it was shown that by simply modifying the surface in this way every single hydrogen molecule hitting the surface of Nb or

Ta (under the experimental conditions used) would dissociate and enter the metal, as compared to approximately 5 in every thousand for clean Nb with no Pd overlayer. This result has important implications for the problem of hydrogen storage because it promises to provide a way to improve the storage process by making composite systems with the advantages of one material at the surface combined with the advantages of another material for the bulk.

This progress in understanding was a consequence of experiments by M. A. Pick *et al.* of the Metallurgy and Materials Science Division in collaboration with M. Strongin *et al.* of the Physics Department. These experiments employed the tools of modern surface science, such as ultrahigh vacuum conditions, Auger electron spectroscopy, low-energy electron diffraction, etc., to provide well-characterized surfaces of highly pure Nb and Ta foils, to which thin metallic overlayers could be added if desired. Hydrogen uptake and emission rates were then measured as a function of temperature and hydrogen pressure. It was found that a layer of Pd *less* than one monolayer thick will either not change or even inhibit the hydrogen uptake, whereas a layer *over* one monolayer thick will enhance the sticking coefficient to a value of 1.[2] The sticking coefficient is a measure of the number of hydrogen atoms entering the bulk compared to the number of hydrogen molecules hitting the surface (multiplied by two, to take into account the dissociation into two atoms). The change at about one monolayer is related to a phase transition of the Pd surface layer at that coverage.[3] In this structural change of the overlayer, the Pd goes from a commensurate structure on (110) Nb and Ta to (111) fcc Pd for thicker layers. Figure 5 illustrates this dependence of the sticking coefficient on the thickness of the Pd overlayer.

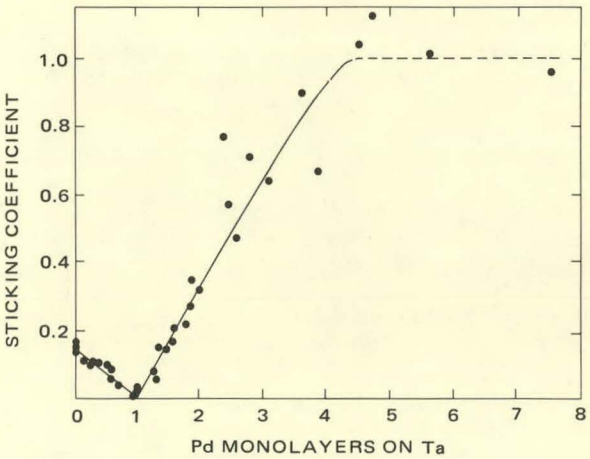

Figure 5. The sticking coefficient of hydrogen on Ta is changed by the deposition of Pd monolayers on the Ta surface.

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MATERIALS FOR SOLAR ENERGY

In the Solar Materials Program, studies of thin-film amorphous semiconductor alloys demonstrated interesting optoelectronic and microstructural properties of potential significance to photovoltaic conversion, xerography, and a variety of photoelectronic semiconductor devices. In order to investigate such plasma-deposited materials, a multidisciplinary, integrated effort has been mounted that consists of i) studies of the plasma chemistry, ii) control of plasma processing conditions, and iii) film growth and characterization. Striking modifications in optoelectronic behavior of the amorphous semiconductor alloys were observed as functions of impurity incorporation. Such impurities include oxygen, nitrogen, carbon, and even chlorine. In particular, alloys that are deficient in either, or both, nitrogen and oxygen impurities exhibit anomalous features in photoconductivity versus reciprocal temperature. By contrast, unusually high photoresponse results from synergistic effects of incorporated oxygen and nitrogen. By comparing the electrical characteristics of alloys produced under low-impurity conditions versus materials produced with calibrated amounts of incorporated impurities, it was found that the usual silicon-hydrogen alloy a-Si:H should more properly be regarded as the alloy a-Si:(H,O,N,C,...).

Diagnostic methods, together with techniques probing basic processes, are currently being used to study all phases of film growth. For example, the physical and chemical processes of plasma deposition are studied by means of optical emission spectroscopy and mass spectrometry. The nature of chemical bonding in as-deposited films is probed by infrared transmission and by Raman spectroscopy. The microstructure of amorphous alloys is investigated using scanning electron microscopy, scanning transmission electron microscopy, and the electron microprobe. Studies include fracture surfaces and nucleation properties of films. Electrically-active defects in films that can limit photovoltaic conversion efficiencies are of particular interest. Such defects are studied by measurements of photoconductivity, photoluminescence, and by the fabrication of developmental photovoltaic devices. In the last case, illuminated I-V characteristics and spectral response data are obtained for diagnostic amorphous semiconductor solar cells. Preparations are in progress for structural and electronic studies of amorphous alloys at the National Synchrotron Light Source.

PROCESS SCIENCES DIVISION*

Materials for Geothermal Energy Processes

Brookhaven National Laboratory's (BNL) expertise in metallic and nonmetallic (plastics, polymer concrete, etc.) research has led the U.S. Department of Energy (DOE) to request the development of materials for geothermal applications.[1,2] Many geothermal brines are highly corrosive and impose severe problems on equipment such as drill bits, casing, cements, piping, and heat exchangers.

Research and development work on improved metallic alloys, polymers, elastomers, cements, and polymer cements is in progress. The work is performed in cooperation with universities and with private industry.

Long-term testing of materials is under way at many U.S. and foreign geothermal sites (Fig. 6). Based upon the results from laboratory and field tests and economic studies performed concurrent with the research, near-term uses in elec-

*Some of this division's work is also presented in the Energy Technology section.

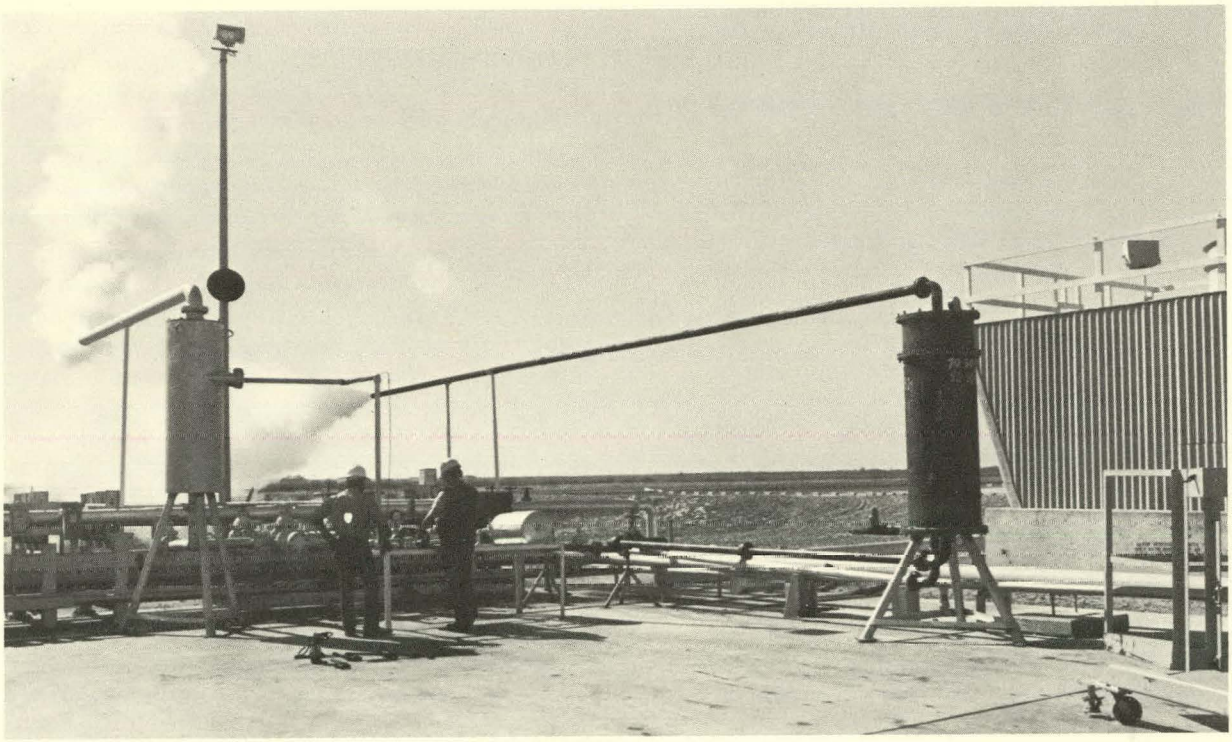

Figure 6. Polymer concrete-lined steel vessel (right center) being evaluated in the Imperial Valley of California for use in separating steam from geothermal brine.

tric generation and space heating appear practical. The results from the work will also result in improved materials for use in the drilling of deep oil and gas wells and in enhanced oil-recovery processes.

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Chemical Synthesis of Polysulfones

The synthesis of ethylene-sulfur dioxide copolymers has been accomplished with ^{60}Co gamma radiation and electron beam radiation with very high yields. The characterization of the ethylene polymer for a low cost commercial plastic is being evaluated with industry. Additional benefits of developing this polysulfone polymer include energy conservation and converting of major pollutant SO_2 into a useful product.

Environmental Control Technology for Atmospheric CO_2

An investigation is being conducted of methods for removal and disposal of CO_2 to prevent atmospheric buildup resulting from the combustion of fossil fuels. A large increase in CO_2 might result in a catastrophic climatic effect (greenhouse effect). The study indicated that removal of CO_2 from the atmosphere is energetically not feasible with a fossil-fueled power source; more CO_2 would be generated than removed. Removal of CO_2 from fossil-fueled power plant stacks is feasible; however, severe efficiency and economic penalties would be paid.

Environmental Sciences

Programs relating to the environment and the impact of energy-related activities upon it are organized in four areas: Environmental Chemistry, Atmospheric Sciences, Oceanographic Sciences, and Land and Fresh Water Environmental Sciences.

ENVIRONMENTAL CHEMISTRY DIVISION

The Environmental Chemistry program has placed emphasis on developing highly sensitive techniques for measuring gaseous pollutants, and methods for determining the size distribution and molecular composition of ambient aerosols, on theoretical studies and laboratory measurements of properties of aerosols, on modeling the chemical reactions of pollutants, on laboratory studies of the mechanisms and rates of fundamental reactions, on field experiments to determine transformation mechanisms and rates of reactions occurring under ambient conditions, and on field experiments to elucidate the interdependence of transport and transformation.

Theoretical Studies include: 1) The construction of a surrogate chemical mechanism which reduces the number of species necessary to model accurately the homogeneous chemistry (in the gas phase) in atmospheric systems. The model involves olefins, ozone, and oxides of nitrogen and sulfur.[1] An extension of the approach has been made to simulate stack plume reactions in order to determine the reaction kinetics influencing the nitrogen and sulfur chemistry within an expanding plume. 2) The effect of the interconnection of mass transport and chemical kinetics upon the uptake and oxidation of sulfur dioxide in aqueous droplets. Application of this analysis to sulfur dioxide in clouds or fogs indicates that mass-transport limitation is not significant except for very high oxidation rates. 3) Development of a mathematical formulation needed for the computation of the collision rates between free molecular and transition regime particles, with attractive, singular contact potentials, based upon the Fuchs method for computation of the coagulation coefficient with no interaction potential. This new method was next used to calculate the collision rate enhancement of water droplets because of their Lifshitz-van der Waals force attraction.

Measurement Methodology includes: 1) The construction, automation, and testing of a real-time photometric detector system for measurement of ambient levels of aerosol sulfur which has demonstrated a capability to determine sulfur[2] down to 0.1 part per billion (10^{-10}). 2) Methods for atmospheric samples developed to determine nitric acid by a filtration technique, nanogram quantities of nitrate by derivatization gas chromatography, and ammonia by fluorescent derivatization. 3) Development of a novel laser heterodyne interferometer employing Stark tuning to measure trace gases in the atmosphere below the part per billion level. 4) Development of an atmospheric tracer sampler, based upon use of multiple perfluorocarbons, that employs fully automated laboratory chromatograph procedures. Determination of these compounds can be made with a sensitivity in air of 1 part in 10^{15}.

Laboratory Determinations include: 1) Measurements of deliquescence properties for single and mixed-salt aerosols composed of chlorides, sulfates, and nitrates whereby a threshold humidity was determined which marks the transition of a solution droplet to a crystalline particle.[3] 2) Construction of a discharge flow-resonance fluorescence apparatus and measurements of the absolute bimolecular rate parameters for gas-phase reactions of the ground-state oxygen atom with organic sulfur compounds.[4] 3) An investigation which has shown an unsuspected dependence of the equilibrium constant for the reaction $2HNO_2 = N_2O_3 + H_2O$ upon acidity at high acid concentrations, thereby permitting the correct evaluation of Henry's law coefficients for NO_2, N_2O_3, and N_2O_4. In addition, we have discovered a first-order rate law for the reactive dissolution of NO_2 into water that is dominant at low NO_2 partial pressure and have determined the mixed-phase rate constant. 4) Developments in an explosive-tagging program that show that

blasting caps and bulk explosive can be detected by screening luggage on a conveyor belt or as a clandestine bomb on board commercial aircraft. 5) A program examining the interaction of concentrated sulfuric acid and water directed toward evaluation of the effect of accidental large scale release of sulfuric acid during shipment on inland waterways. This program has led to the development of a mathematical model to characterize the turbulent mixing of sulfuric acid in stagnant water. A spill facility was constructed and experiments were performed that have validated the model.

Field Studies have been performed which include: 1) A diagnostic experiment designed to test the proximity to phase equilibrium of the H_2O-NH_3–HNO_3– aerosol (sulfate and nitrate) system in the ambient environment. 2) An intercomparison of filter and real-time methods for the measurement of sulfur, sulfate, and mass in ambient aerosols, and a second experiment to intercompare methods for nitric acid and aerosol nitrate. 3) An examination of results for more than 50 plume studies for trends relating sulfate formation to meteorological conditions. Although no strong correlations were delineated, it could be concluded that most measurable oxidation of sulfur dioxide occurred during daylight hours.[5] 4) Measurements of power plant emissions at oil-fired operations which have led to a means of predicting sulfuric acid emissions as a function of operating parameters. Recommendations for limiting sulfate formation have been made and these include operation with very low furnace oxygen, adequate use of magnesium oxide additive, and use of efficient electrostatic precipitators for removal of particulate matter. 5) Establishment of an experimental direction center at BNL to provide meteorological forecasts for a North East Regional Oxidant Study (NEROS) and direct the operations of aircraft involved in the air sampling program. In addition, an instrumented aircraft for chemical and meteorological measurements was operated by BNL.

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ATMOSPHERIC SCIENCES DIVISION

The atmospheric sciences research is aimed at the development of the knowledge needed to do realistic evaluations of the effect of energy production upon air quality. Part of the program examines air pollution problems directly, such as the transport and transformation of trace materials in the atmosphere, and the delivery of pollutants to environmentally sensitive receptors. Other research attempts to understand basic meteorological processes. The Multistate Power Production Pollution Study (MAP3S) is conducted in cooperation with other laboratories. Goals are an assessment of the effects of the long distance transport of pollutants and of the deposition of acid material on the surface, (i.e., "acid rain"). The coastal meteorology program is aimed at understanding the complex processes that occur at the land-sea boundary and at the air-sea interface. Aspects of these two programs are briefly discussed below.

A study of precipitation chemistry and its relationship to meteorological conditions has been in progress since 1976.[1-3] This is one of several precipitation sampling programs initiated in response to the "acid rain" problem in the Northeastern United States but is unique in two ways. First, it is the only program in which precipitation is sampled on an hourly basis during every precipitation event, using an automatic sequential precipitation sampler designed and built at the Laboratory.[4] Secondly, it is the only program in which the meteorological conditions prevailing at the time of each sample are recorded and

analyzed to determine the effects of these conditions on precipitation acidity and chemical compositions. Since meteorological conditions are often very different from one event to another and often change significantly during the course of a single event, such studies are not possible in other programs taking event or weekly samples.

Analysis of our data has revealed many significant and previously undocumented relationships. For instance, pH is lowest (acidity highest) in the summer, highest in the winter, and intermediate during spring and fall months (Fig. 7). The low summer pH is related to the prevalence of slow-moving or stagnant polluted air masses at that season. pH is also lower in thunderstorms and rain showers than in general rains and is lower with cold-front than with warm-front rains. These differences are related both to the dynamics of these storm systems and to their seasons of most frequent occurrence.

pH increases with both duration of precipitation and with precipitation rate (Fig. 7). The former demonstrates a cleaning of the atmosphere as precipitation falls through it, and suggests that pollutants are removed from both below the cloud and from within the cloud during the early stages, but largely from within the cloud after the lower atmosphere has been cleansed of pollutants. The higher pH with greater precipitation rates suggests that available pollutants are more diluted in heavier rains but give higher concentrations when rainfall is light.

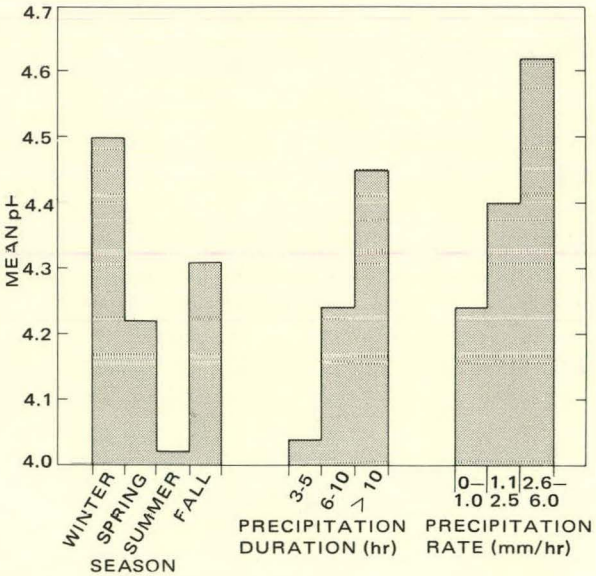

Figure 7. Variation of pH with season, precipitation duration, and precipitation rate.

Marine boundary layer experiments were conducted over the Bay of Bengal at Digha, West Bengal, India as part of the International Monsoon Experiments (MONEX 79). The purpose of these experiments was to understand the Bay of Bengal cyclogenesis during the southwest monsoon and to study the air-sea interaction processes over a tropical ocean.[5] The experiments consisted of measurements of atmospheric turbulence, and fluxes of momentum, heat, water vapor from a 10-m high coastal meteorological tower (Fig. 8), mean meteorological parameters with an automated electronic weather station, and wind speed and direction profiles with pilot balloon soundings.

Figure 8. Instrumented meteorological tower at the beach.

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OCEANOGRAPHIC SCIENCES DIVISION

In response to concern about the environmental consequences of energy-related activities, the Oceanographic Sciences research group continued the study of the Northeast coastal marine ecosystem. In collaboration with other researchers at the Woods Hole Oceanographic Institution, Lamont-Doherty Geological Observatory, State University of New York at Stony Brook, NOAA-National Marine Fisheries Service Laboratories in Massachusetts, Rhode Island, and New Jersey, and the NOAA-Atlantic Oceanographic Meteorological Laboratory in Florida, the BNL oceanographic program has conducted

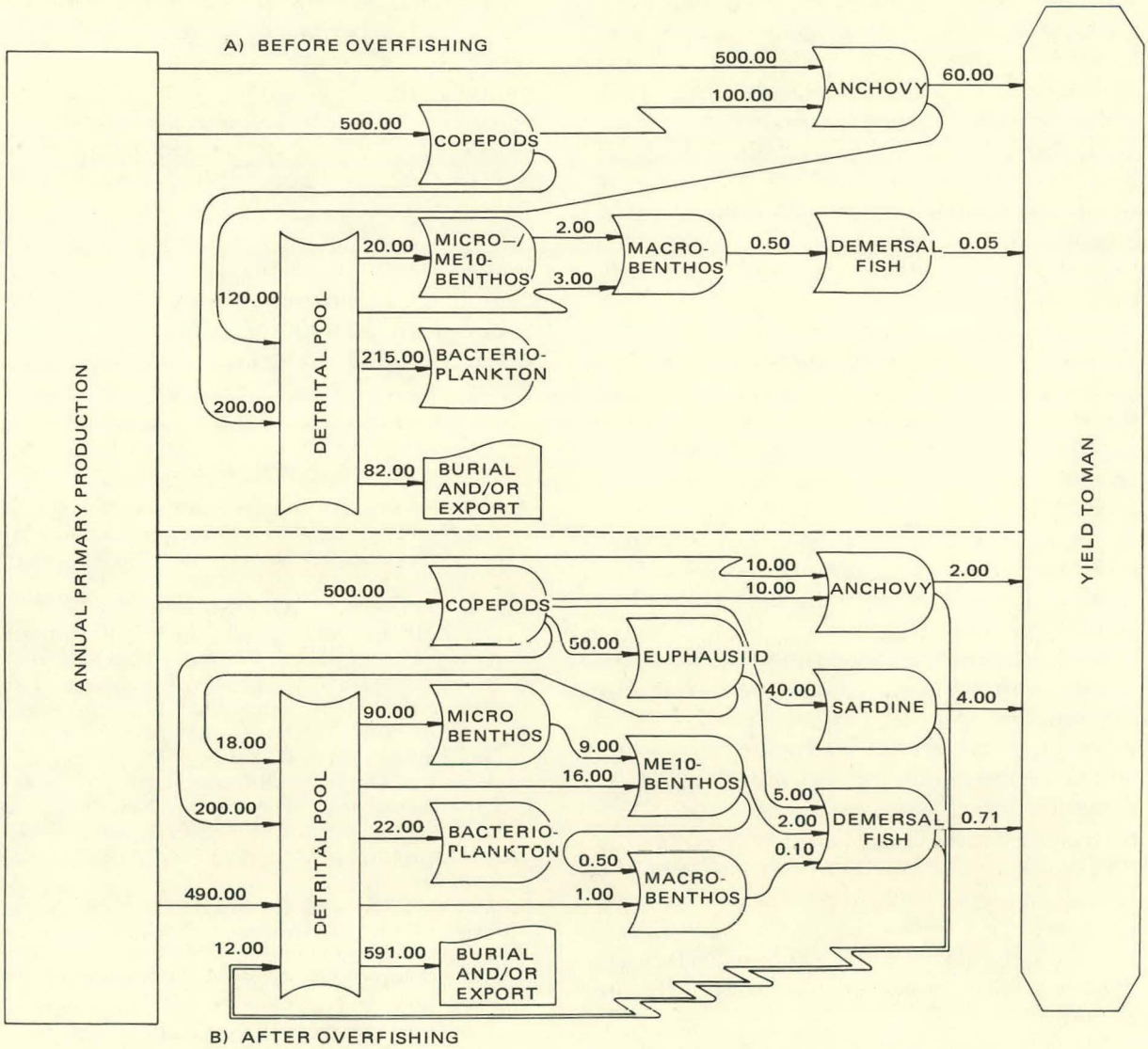

Figure 9. A carbon budget (g C m^{-2} yr^{-1}) of yield to man on the Northeast continental shelf.

50 cruises over the last 5 years to provide data on nutrient fluxes to primary producers and their subsequent utilization by dominant herbivores for the coastal region from Cape Hatteras to Georges Bank.[1,2]

From the vast amount of collected data, during the last year we have been able to construct the annual carbon budget of the coastal food web in the New York Bight (Fig. 9). This carbon budget suggests that the flux of particulate matter through the pelagic herbivores and thence pelagic fish occurs mainly in the summer-fall, while carbon flow is directed to the food web leading to demersal fish in winter-spring.[3] The residence time and fate of this organic matter, sinking to the shelf sediments, are important in terms of both dispersal of pollutant energy-related particulates and as an intermediate sink in the global CO_2 cycle. Approximately half of the carbon fixed by the phytoplankton in this region, not including the richer areas of Georges Bank and the Hudson River plume, appears to sink to the bottom, but not be consumed by the benthic community. Since there is little carbon in the sediments of the northeast continental shelf, the organic matter, like fine grain sediments, may be transported off the shelf to the upper slope, where the high concentrations of carbon are found in the sediments. Carbon export from the shelves is not a new sink for CO_2, but a neglected one that could be impaired if energy-related pollutants were to disrupt the normal food chain relations of the coastal zone.

The large data base was collected as input to computer models of the coastal food web, within which natural and man-made perturbations could be examined.

In an attempt to quantitatively relate changes in carbon fluxes to variations of the wind forcing, simple models were constructed of the wind driven water circulation to separate conservative and non-conservative factors controlling the distribution of biological variables. Our initial effort was a depth-integrated, one-layer description of the barotropic flow, with inclusion of a time-dependent wind stress, bottom topography, and the Coriolis force.[4] We were able to predict the probability of a winter oil spill reaching Long Island beaches from various offshore locations.

For summer conditions, a two-layered diagnostic circulation model, which incorporates the density field and current meter data, was then applied to the 1976 anoxic event off New Jersey, where the "normal" summer carbon flow to the pelagic herbivores (Fig. 9) was interrupted by the introduction of a non-edible form of phytoplankton known as *Ceratium tripos*.[5,6] Incorporation of biological terms in the diagnostic circulation model allowed us to simulate the transport and respiration of the *C. tripos* populations. The predicted subsurface depletion of oxygen in 1976 agrees with observations,[7] suggesting that the cause of anoxia was not anthropogenic energy-related pollutants, but a consequence of normal physical and biological interannual variability of the coastal ecosystem.

Additional progress was noted in the MESEX (Mesoscale Experiment) project where 4 current-meter moorings, an *in situ* fluorometer mooring, and shipboard sample collections investigated the spatial and temporal distribution of temperature, salinity, and chlorophyll fields in the nearshore region off Tiana Beach, Long Island. A comparison of the observed variability in chlorophyll concentration with measured laboratory feeding rates of zooplankton allows the degree of zooplankton-phytoplankton coupling to be estimated for this nearshore area. An additional MESEX II experiment is being planned for an estuary plume to investigate the possible influence of any energy-derived pollutants.

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Sensitivity of the Eastern U.S. to Acidic Precipitation

Substances harmful to the environment, emitted by fossil fuel combustion, are deposited over geographically large areas and have resulted in the acidification of surface waters in many regions of North America.

A study has been carried out to define and map areas of the eastern United States which may be sensitive to acidification.[1] Vulnerability is based largely on the chemical characteristics of the bedrock. Limestone terrains present "infinite" acid-neutralizing (buffering) capacity to acidic precipitation, whereas granites (and related igneous rocks), their metamorphic equivalent, and noncalcareous sandstones provide only minimal buffering. Analysis of geologic terrain was undertaken on the scale of the most recent state geologic maps. Rock formations have been classified according to their potential buffering capacity. Extensive surveys of surface waters with alkalinities < 200 micro-equivalents per liter (μ eq/ℓ) in North Carolina and New Hampshire, conducted in 1979, found 83-100% of these sites were located in geological regions which contained rocks deficient in chemical buffering capacity. Information obtained from numerous sources of raw data and from computerized data bases was used to establish the Acidification Chemistry Information Data Base (ACID). This was used to plot surface water alkalinity on a county-by-county basis. This map, which for testing purposes was considered to be the "correct" map, was compared to the geologically-based map definitions of sensitive areas for each county in North Carolina and New Hampshire. The geologically based sensitive areas map was "correct" for 71% of all counties in ACID which had alkalinities ≤ 200 μ eq/ℓ.

Effects of Acid Rain on Crops

Experiments conducted in an agricultural field using standard agronomic practices as well as in a greenhouse show that seed yields of soybeans and pinto beans were reduced when exposed to rainfall solutions at and slightly below the acidity of rainfalls that occur in the northeastern United States.[2,3] The decrease in seed yields was attributed to a decrease in the number of seed pods on a per plant basis. The weight of each seed or the number of seeds per pod did not change. The results suggest that additional increments of rainfall at pH levels below 4.0 may cause reductions in soybean yields of from 3 to 7% (Fig. 10).

An alteration in the rates of gas exchange also occurred in plants exposed to acidic precipitation. Rates of gas exchange were higher in plants exposed to more acidic precipitation, even at acidic levels that had no visible injury. The data suggest that plants exposed to acidic precipitation are more sensitive to gaseous pollutants than plants not exposed.

Effects of Acid Rain on Soil Microbial Processes

Effects of soil acidity on microbial decomposition of organic matter and transformation of nitrogen in an acid forest soil were investigated.[4] Ammonification and nitrification in the naturally acid and pH-adjusted acid soils were determined by monitoring the ammonia and nitrate formation on a periodic basis. In addition, the contributions of nitrate from heterotrophic microbial communities in naturally acid and pH-adjusted acid soils were examined. Ammonia formation in the pH-adjusted acid soil was about 50% less than in the naturally acid soil. Increased

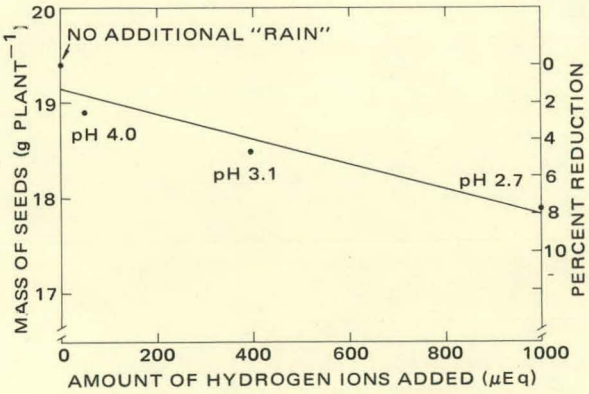

Figure 10. Change in soybean seed yield with different application of simulated acid rain, in field experiments using standard agronomic practices.

rates of ammonification and nitrification were observed in the pH-adjusted neutral soil. Little autotrophic and heterotrophic nitrifying activity was detected in naturally acid and acidified forest soils. Soil enzyme studies indicate no apparent differences between the urease and dehydrogenase activities in the natural and pH-adjusted neutral soils. A naturally acidic soil which was further acidified exhibited much less urease and dehydrogenase activities.

The effect of pesticides 2,4-D, cacodylic acid, Dylox, Methoxychlor, Sevin, and Paraquat on soil microbial activity and the fate of 2,4-D, Sevin, and Paraquat in naturally acid and pH-adjusted acid and neutral soils were investigated. The data suggest that the addition of these compounds to soils did not have any effect on soil respiration. However, variations in the rate and degradation of 2,4-D, Sevin, and Paraquat were observed. Paraquat was not degraded in acid soils.

Human Virus in Groundwater Recharge Systems

A 3-year program investigating the ability of a well-managed tertiary sewage effluent recharge system to return microbiologically acceptable water to the ground aquifer was completed.[5,6] The study demonstrated the overall success of a tertiary system in removing human viruses, although viruses occasionally reached the aquifer. The incidence of viruses in sewage effluent and renovated waters was found to be correlated with the presence of coliform bacteria. Rates of virus removal during soil percolation were inversely related to infiltration rates and the adsorption efficiencies to soil were found to be strain-dependent.

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Energy Technology Programs

The Energy Technology Programs are directed to the development of advanced energy systems and components. Emphasis is placed on technologies that offer significant improvements in energy conversion and storage systems, the utilization of abundant and renewable sources, and significant improvements in environmental characteristics. Concepts that advance the state-of-the-art beyond that required by current or contemplated standards are of primary interest.

OIL REFIT PROGRAM

The Brookhaven National Laboratory Oil Refit Program provides technical support for the U.S. DOE Fuel Oil Conservation Marketing Demonstration Program and is designed to accelerate the use of fuel-saving devices and systems by homeowners. BNL is monitoring the results of the New York State Pilot Marketing Demonstration Program which it planned and implemented. The data collected on the retention head burner have firmly established that this device saves ~15% of the annual fuel consumption. BNL has also planned and is implementing the Oil Refit Option Qualification Program involving procedures for evaluating other refit options.

HYDROGEN STORAGE TECHNOLOGY

BNL has completed the design, construction, and instrumentation of the Hydrogen Technology Advanced Component Test System (HYTACTS) and passed a major DOE milestone by having available a facility for testing hydrogen storage vessels for metal hydrides or other systems on an engineering scale. Hollow glass spheres were identified as a potentially effective means for storing hydrogen.

HEAT PUMP SYSTEMS

During the course of the year, BNL assumed the major responsibility for development of chemical heat pump systems for DOE. These systems have potential application for heating and cooling in buildings and recovery of waste heat in process systems. Such systems may be driven by solar input in the heating and cooling applications.

ELECTROCHEMICAL TECHNOLOGY

In the basic and applied research, relevant to the development of advanced fuel cells, water electrolyzers, and batteries, the electrochemical group has shown that (1) regenerating the electrocatalytic activities of aged fuel cell electrodes in phosphoric acid is feasible using fast potential cycling, (2) the rate of oxygen reduction in phosphoric acid is enhanced by the addition of small amounts of trifluoromethanesulfonic acid, and (3) a ruthenium-base mixed oxide ($RuIr_{0.5}Ta_{0.5}O_x$) is an excellent electrocatalyst for oxygen evolution in solid polymer electrolyte water electrolyzers. Alkaline fuel cell modules (up to 1/2 kW) were designed, fabricated, and tested in the program "Development of Fuel Cells for Vehicular Applications." Alternating and direct current techniques were used to elucidate the kinetics of oxygen evolution and reduction in zirconia/yttria electrolytes at 1000°C. The kinetics of this reaction were found to depend on the catalytic properties of the electrode materials. A rapid electrochemical method was developed to determine oxygen transport rates through oxides and metals. New approaches were developed to elucidate the contributions of the separator and electrode additives in prolonging the cycle life of nickel-zinc batteries.

FOSSIL ENERGY TECHNOLOGY

The Fossil Technology Program which has grown steadily during 1979 now involves project components and staff in the Energy Sciences, Environmental, and Technology areas of the Department, as well as the National Center for the Analysis of Energy Systems. The effort concentrates on the technology of catalysts which play a role in the indirect conversion of coal to diesel and jet fuels, and diesel-soot studies. Hot

gas cleanup including desulfurization of gases in fluid beds, particle mass monitoring for potential application in combined cycle systems, and coal gasification, using hydrogasification and alternative techniques, are being studied. Combustion, in particular the use of coal-oil mixtures (COM) in industrial boilers and furnaces, is receiving special attention.

Accomplishments in these activities are described in the sections which follow.

Flash Hydropyrolysis of Coal

This project utilizes a small pilot plant facility to investigate the direct hydrogenation of coal to liquid and gaseous hydrocarbons.[1]

In the parametric study with non-caking lignite coal conversion of 90% of the coal to liquids and gases was obtained. Conditions which maximize yields of either liquids or gases were established. Coal pretreatment, to render coals non-caking or to improve the gas yields, was explored. A kinetic model was developed for lignite hydrogenation, and was applied to preliminary process designs for the production of gas, liquid, or a mixture of both.

Alternative coal gasification techniques were studied to improve conversion efficiencies and/or reduce capital cost.[2] In an initial study, gas separation schemes for catalytic gasification and hydrogasification systems were compared with the use of gas hydrates (clathrates) and absorption and were found to be the more efficient technique.

Sorbents for Gas Clean-Up

In the project "Regenerative Processes for Desulfurization of Combustion and Fuel Gases" a new class of sorbents based on calcium silicates was identified and evaluated.[3,4] Techniques for preparing agglomerated pellets of Portland cement, which is the principal component of the sorbent, have been developed. Sorption and regeneration of the material occurs in the same temperature regime.

The desulfurization of combustion gases was studied as a chemical process, using the rotating fluidized bed as a sorption reactor. Smaller sorbent particles with more usable active surface can be held in the rotating bed, while higher gas velocities and reaction rates can be maintained than is possible in the stationary fluid bed. Initial results have shown that sorbent utilization is high, particle losses small, and rates of removal high. SO_2 removal from high temperature gases is better than 95%.

Catalysis

A new explanation of the mechanism for the catalytic conversion of syngas to methanol and higher hydrocarbons[5] has resulted in a project to study the conversion of syngas to diesel and jet fuels. Fundamental to this understanding is that chemisorbed carbon monoxide reacts with hydrogen over metal surfaces yielding an oxygen- rather than a carbon-coordinated species. The metal-oxygen bond thus formed will determine the reaction characteristics. This postulate provides a framework for the design of experiments and the development of new catalysts. The associative adsorption of carbon monoxide on the oxygen of metal oxide surfaces is the major postulate used to explain the catalytic formation of methanol.

The mechanism of soot formation in diesel engines was modified using a catalyst. Initial results led to the preparation of a program for a study of the phenomena in more detail.[6] The initial work made use of an available CFR engine.

Combustion

Studies in a Coal-Oil Mixure (COM) Combustion Project have shown the need for research in areas which have not been investigated in enough detail to insure success in application.[7] A proposal was submitted to develop a COM technology by doing engineering studies directed toward use of the fuel in BNL boilers and elsewhere. The study dealt with COM transportation and storage stability, as well as combustion. BNL is the technical project office in the boiler/furnace project, and is making a study of the technological factors involved and the potential for resolution of barriers to the introduction of coal in the industrial and commercial sectors. BNL also provides analytical support to DOE-NCAES data base, computer models, and analytical techniques.

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SOLAR ENERGY TECHNOLOGY

Activity in the solar heat pump program proceeded in two areas: (1) the identification of optimum system configurations, including specification of the characteristics and allowable cost of the various system components — heat pump, storage, alternate heat source, solar collectors, and other system components; and (2) the development of the required components, both through work conducted at BNL and through work proceeding elsewhere under DOE contracts managed by BNL.

In the area of system optimization, three significant accomplishments can be listed:

1. Development of a simple analytical method for optimizing solar assisted heat pump systems;
2. Development of a computer program to model in-ground heat transfer, and the integration of this model into the widely used solar simulation program Transient System Simulations (TRNSYS).
3. Establishment of benchmark economic criteria for allowable solar collector costs.

The accomplishments achieved in the technology area are:

1. A low cost collector design was developed which uses thin-film plastics in both the absorber and glazings. This design is projected to be consistent with the cost constraints.
2. The first year of operation of the ground coupling experiment showed that acceptable rates of heat transfer can be obtained, and data were collected to make possible the preparation of preliminary design guidelines.
3. The ability of vapor-compression heat pumps to provide high efficiencies in the upper end of the 4-38°C source temperature range was demonstrated. This temperature range is appropriate for solar-assisted heat pump operations.

In addition to the solar-assisted heat pump work, other experiments were conducted on solar activated cooling devices. Specifically, measurements were carried out on a commercially available 3-ton solar-fired absorption chiller to determine the steady-state and transient operating characteristics of this device. As a result of these measurements, a simple control modification was invented which greatly reduced the losses in efficiency caused by on-off cycling under part-load conditions.

ENERGY CONSERVING ARCHITECTURE

Progress was made in a new program directed toward identification of architectural design practices for conservation of energy in residential buildings. A general study was completed of ways to utilize thermal storage mass in houses to reduce heating energy needs. This led to design of a house, suitable for tract builders, with only one-third of the annual energy use of typical modern, energy-efficient houses. A contract was placed for construction of the first model of the house at Brookhaven. (Fig. 11).

Figure 11. Energy Conserving House.

National Center for Analysis of Energy Systems (NCAES)

The National Center for Analysis of Energy Systems performs quantitative, interdisciplinary studies of the technological, economic, social, and environmental aspects of energy systems.

The emphasis of the programs at the Center is on energy policy and planning studies at the regional, national, and international levels. Development of planning framework, analytical models, data bases, and assessment methods provides the foundation for the energy studies. Thus, the program involves both operational support to DOE and original research in energy systems analysis.

During 1979, the Center continued its basic program of quantitative, integrated studies of the energy system and its interactions with economic, environmental, and social systems. Increased attention was given during the year to more detailed analyses of specific policy issues and energy supply/demand subsystems and technologies, with emphasis on assessment of the environmental impacts of energy supply systems, and analysis of the technology and economics of energy conservation and solar energy.

METHODS AND DATA DEVELOPMENT

The development and maintenance of a comprehensive set of data bases and energy models providing an integrated framework for analysis has long been central to the energy analysis program at BNL. As part of an international cooperative effort housed at the Center and sponsored by the International Energy Agency (IEA), Market Allocation Model (MARKAL),[1] a multiperiod linear programming model, has been developed, and the technology data base has been updated and expanded; during 1979, the development effort was essentially completed, and each of the participating IEA countries used MARKAL to assess the role of new energy technologies within each specific national energy system. A dynamic or "time-stepped" model, TESOM, was also developed to provide a "rational expectations" alternative to clairvoyant optimization models such as MARKAL; this model includes a demand elasticity representation algorithm,[2] and has been linked with the socio-economic model of Dale Jorgenson and Associates (DJA) for the purpose of assessing the long-term interactions between energy strategies, technology, and the economy. Because energy options cannot be evaluated in single-dimensional terms, techniques for quantifying the tradeoffs among various objectives have been investigated.[3]

During 1979, the Center's capabilities in data system design were used in a DOE program involving the organization and documentation of national data, as part of the Energy Emergency Management Information System (EEMIS) being developed by the Energy Information Administration (EIA).[4] The Center also designed a format for collecting and documenting data characterizing diverse energy technologies in a way that would allow consistent treatment of these technologies in various models and analyses.[5]

ENVIRONMENTAL ASSESSMENT

At the NCAES, work has been under way for several years to identify and, where possible, quantify the damages and risks associated with existing or proposed systems for extracting, converting, transporting, and using energy in its many forms.

As part of this program, new statistical relationships linking socioeconomic factors and air pollution from energy sources to cardiovascular mortality have been found.[6,7] An analysis was completed in 1979 that provides a relatively simple method for estimating population exposure from site-specific power plant air pollution emissions in the eastern U.S.[8] In a related project, a detailed analysis of carbon dioxide emissions from a solvent-refined coal (SRC) plant was carried out, emission levels compared with direct combustion of fossil fuels, and the contribution of a major synfuels program to global CO_2 estimated.[9]

A county level water quality data base was constructed, validated, and used to examine rela-

tionships between water quality and natural, residential, and industrial factors, providing new insights into relationships between energy activities and environmental impact.[10]

REGIONAL ASSESSMENT

The Center continues to have a major program focused on regional and site-specific analysis of energy policies and scenarios.[11-13] As part of the Regional Issue Identification and Assessment (RIIA) Program, the Center assessed the impact of increased coal use on the Northeast in 1979. The Center's role in RIIA was expanded to include assessment of the solid waste implications for the entire U.S. at the county level, and an in-depth environmental assessment for the Northeast United States.[14]

CONSERVATION AND SOLAR ENERGY

Analyses of various aspects of energy conservation and solar energy was a major part of the NCAES program in 1979. These activities ranged from assessment of the macroeconomic effects of a national energy strategy emphasizing conservation and solar energy,[15,16] to analyses of the technical and economic feasibility of self-contained solar energy systems for homes.[17]

In order to help identify specific opportunities for solar and conservation, one program in the Center is developing detailed computer models of the technical processes and energy use in particular energy-intensive industries; during 1979 the model of the pulp and paper industry was completed and transferred to DOE.[18] The use of vehicles in fleets is being analyzed in order to determine how the special characteristics of fleet operation might be exploited to encourage adoption of innovative vehicle concepts.[19]

INTERNATIONAL PROGRAMS

On the international front, NCAES has for several years been involved in studies related to the energy situation in other countries.[20] During 1979, the Center continued its participation in these programs, such as DOE's International Energy Development Program (IEDP), U.S. AID's Energy Management Training Program (EMTP), and the IEA cooperative R&D analysis program. In addition, a program of technical assistance for energy analysts in foreign research institutions was continued.

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J. Lofstrand, Oceanog.
S. Malloy, Oceanog.
T. Owens, Oceanog.
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G. Rowe, Oceanog.
S. Smith, Oceanog.
I. Snapper, Comp. Sci. Anal.
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C. Krishna, Mech. Eng.
P. Marnell, Chem. Eng.
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H. Serry, Chem. Eng.
W. Slegeir, Chem.
J. Wegrzyn, Phys.

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G. Mitchell, Econ.
V. Mubayi, Phys.
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A. Kydes, Math.
J. Martorella, Sys. Anal.
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K. Novak, Com. Health Assoc.
C. Robinson, Math.
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H. Thode, Math.

Technology and Data

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R. Bright, Sys. Eng.
J. D'Acierno, Sys. Eng.
A. Hermelee, Sys. Eng.
J. Lamontagne, Sys. Eng.
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R. Pouder, Sys. Eng.
A. Queirolo, Sys. Eng.
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Department of Nuclear Energy

INTRODUCTION

The Department of Nuclear Energy (DNE) conducts programs concerned with energy sources derived from the atomic nucleus. The program areas with which DNE is involved are: advanced reactor systems; safety of fission reactors; evaluation of nuclear reaction cross sections; nuclear waste management; and nuclear materials safeguards, both domestic and international. These areas are assigned to divisions within the department. DNE is unique among the research departments in that the bulk of its funding comes from the Nuclear Regulatory Commission (NRC) rather than from the Department of Energy (DOE). The present budget allocations are about 60% from NRC, 15% from DOE, and the remainder from other sources.

ADVANCED REACTOR SYSTEMS

Fast-Mixed Spectrum Reactor Program

The Fast-Mixed Spectrum Reactor (FMSR) Program was initiated in 1978 to determine the feasibility of implementing a new breeder concept which has unique proliferation-resistance characteristics. The reactor is capable of operating with a variety of fuel cycles by exploiting its high breeding potential stemming from the use of metal fuel. In a once-through fuel cycle, the reactor has an increased resource utilization factor with respect to light water reactors ranging from five to fifteen, depending on attainable fuel exposures and reactor mix scenarios. In addition to operation with proliferation-resistant fuel cycles, the FMSR can operate as a high gain breeder in symbiotic systems with thermal converters.

Design studies have included both sodium- and helium-cooled reactors. Several optimization studies are under way to determine the best fast-moderation region mix and arrangement. Considerable effort has been directed to cross-check reactor physics and thermal-hydraulic analyses with state of the art methods used at other laboratories. Close liaison has been maintained with the Argonne National Laboratory, Massachusetts Institute of Technology, Oak Ridge National Laboratory, and General Atomic Company. The results to date indicate that feasibility is promising, at least to the extent that aggressive research and development programs in the areas of fuel and materials as well as reactor physics should begin as soon as possible. In other areas, the FMSR is expected to utilize conventional advanced LMFBR or GCFR technology.

NUCLEAR SAFETY

Nuclear safety programs at BNL sponsored by the NRC consist of research to improve understanding of various types of reactors under hypothetical accident conditions, development of computer codes for accident analysis, risk assessment studies, waste management studies, and technical assistance to support the day-to-day NRC reactor licensing requirements. Studies on three generic reactor types, light water, high temperature gas cooled, and fast reactors, include both analytical and experimental work. The experimental work at BNL, it should be emphasized, is not carried out with operating reactors, but may involve use of individual reactor components.

Core Safety and Plant Transient Analysis

The core safety and plant transient analysis programs provide the NRC with the capability of following the behavior of a nuclear power plant during normal and abnormal operation. Calculations were provided for NRC staff to use in assessing the methods and results of reactor vendors and operators, assuring that the necessary degrees of accuracy and conservatism are present.

In some cases, the area of main interest is in the core of the reactor; in others, more of the reactor components must be included. The skills used for these analyses include neutron transport, fluid mechanics, and heat transfer.

For boiling water reactors (BWRs), studies were done of the control rod drop accident. A blade is assumed to drop out of the reactor; the reactivity addition then causes a power surge which is terminated by the negative feedback due to the increase in fuel and moderator temperature and the generation of steam voids. Different reactor conditions and modeling assumptions have been studied. Some of the variables considered are power level, rod worth and speed, flow rate, inlet subcooling, direct energy deposition fraction, and delayed neutron fraction. Emphasis was placed on the effect of moderator feedback which is usually neglected. The degree of conservatism introduced by this assumption was thereby quantified.

For pressurized water reactors (PWRs), a study of power distribution control strategies was completed. When a reactor is in a load-following mode, the power distribution will change continuously due to control rod movement, soluble boron level changes, changes in moderator temperature, and xenon redistribution. Calculations were done to test the different strategies that assure that the power peaking in the core never exceeds specified limits. The calculational model includes a cross section representation with the appropriate feedback coefficients in one dimension for a three loop PWR at end-of-cycle.

Work is continuing to produce data sets so that static and transient safety calculations can readily be done at any point in a fuel cycle for a variety of reactor types. Two-group neutronic data are now available for a three-loop PWR and a BWR/3 design through Cycle 1. Subsequent cycles are being calculated. The BNL system of core-follow codes was updated to make this process more efficient.

Work continues on various topics pertinent to the radiation embrittlement of pressure vessels and shield tanks. The spectral lead factor which helps relate surveillance capsule measurements to pressure vessel fluence has been studied and incorrect procedures used in industry have been identified. The Pool Critical Assembly Pressure Vessel Dosimetry Experiment is being calculated and will be considered as a benchmark. Specific one- and two-dimensional multigroup transport theory calculations of fluences and damage levels are being done upon request from NRC.

Some of the brief studies done to provide NRC quickly with technical assistance when needed are the following: (1) calculations were done to assess the reactivity worth of "crud" deposition; (2) a review was made of procedures for removing fuel bundles and control blades during BWR refueling; (3) after the TMI incident, calculations were done to determine the multiplication constant of clad-free pellets suspended in the coolant; and, (4) calculations were also done to relate the source range monitor readings observed during the accident with different void patterns in the core and downcomer regions.

The plant transient analysis programs provide the NRC with technical assistance in the systems analysis of pressurized water and boiling water reactors. These programs include the development of computer codes and the application of these codes to reactor licensing calculations. A computer code, known as IRT, is being developed for use in licensing and operational transient calculations. IRT has recently been used to analyze the initial phase of the Three Mile Island incident and the computed results are in good agreement with the available data. In addition, the code has been used to evaluate various plant design changes that have been proposed to mitigate the consequences of a Three Mile Island type incident.

Analyses are also being performed to evaluate the effects of ruptured steam generator tubes during various reactor transients, including especially the transient induced by rupture of a main steamline. In the case of the steamline rupture, there is a possibility that the reactor cooling water could pass through the ruptured steam generator tubes and out the steamline break to the atmosphere. The radiological consequences of such a break are being evaluated.

These programs also include providing assistance to the NRC in the evaluation of various operational problems occurring in operating reactors. For example, the recent steam generator tube rupture that occurred at the Prairie Island plant was evaluated using the IRT computer code.

Containment System Integrity

During the past year, the Containment Systems Group has continued to act as a technical consultant to NRC in the area of BWR containment, with specific emphasis on pool dynamic loads. The initiating events which may cause

these hydrodynamic loads are: (1) loss of coolant accident (LOCA) in which case the pool serves as a large heat sink to condense the leaking steam, and (2) safety/relief valve (SRV) actuation whereby the excess pressure in the reactor vessel is relieved by venting some of the steam into the containment pool. In both cases, the flow of steam into the pool would be preceded by air which had initially occupied the volumes of the respective vent systems. Associated with the expulsion of air into the pool are several loads. Figure 1 illustrates some of these loads occurring in a Mark II containment during a LOCA. At later times, during the LOCA event, the fluid entering the pool will be almost pure steam which may condense in oscillating fashion resulting in a periodic pressure loading on the pool walls and submerged structures.

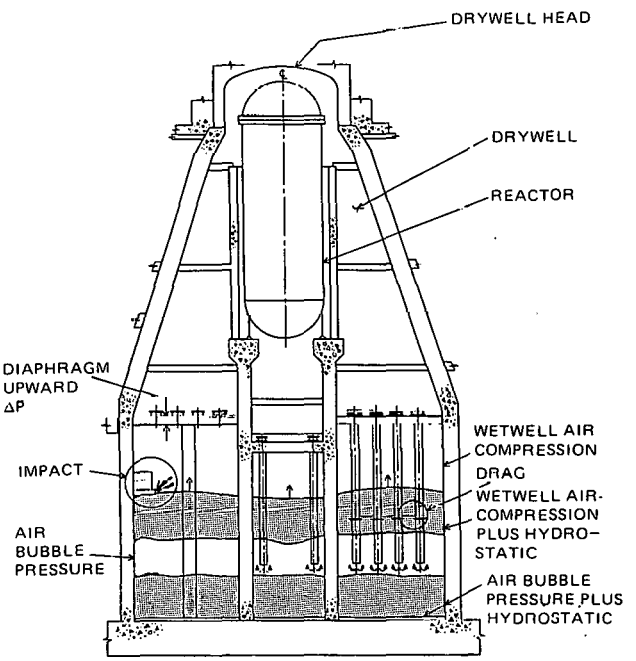

Figure 1. LOCA pool swell loads

In work related to Mark I containments (i.e., operating reactors), BNL staff has reviewed and evaluated the generic load methodologies presented by the Mark I Owners Group and has assisted NRC in formulating Acceptance Criteria on all the containment loads. These criteria were presented to the Advisory Committee on Reactor Safeguards (ACRS) on September 14, 1979. In work related to Mark II containments (reactors undergoing licensing review), the main thrust has been on reviewing results from several pertinent foreign and domestic test programs. Of special interest are: (1) the full-scale, 7-downcomer, simulation of Mark II condensation loads conducted by JAERI (in Japan), and (2) the in-plant tests of safety/relief valve actuation in a real Mark II plant at Caorso, Italy. BNL is advising NRC on the licensing implications of these data for the domestic Mark II plants.

System-Wide Reactor Transient Code

The simulation of a liquid metal cooled fast breeder reactor (LMFBR) system or a light water reactor (LWR) system for a variety of off-normal and accident conditions is an essential part of the overall safety evaluation. Some of the examples of transient conditions of interest include: the withdrawal of control rods; pump seizure in one of the heat transport loops, afterheat (decay heat) removal via natural circulation; and for LMFBRs, a major pipe rupture in the sodium-carrying heat transport system. For any of these disturbances, the system response (i.e., temperatures, pressures, and flow rates at key locations) for the entire plant needs to be calculated to help the NRC in their licensing studies.

To develop analytical tools in this area, the Super System Code (SSC) Project at BNL is funded by the Division of Reactor Safety Research, NRC. This project has two elements, SSC Development and SSC Validation. Under the SSC Development program, work is progressing on four versions of the SSC series of codes. These include: (1) SSC-L, which simulates the thermohydraulic response of any loop-type LMFBR; (2) SSC-P for pool-type LMFBRs; (3) SSC-W for water reactors; and (4) SSC-S for shutdown (i.e., long term) transients of the -L, -P and -W versions. SSC is being developed in a very generalized way. It has been designed to be user oriented, highly modular, and flexible. There is one central program library which contains all the subroutines for the various reactor system components/models, input processing, and output processing. How these computational blocks are interconnected internally in the code, and what input is used, distinguishes one version of SSC from another.

The SSC-L code has been operational since September, 1977. Reports describing not only the models and methods employed,[1] but also

detailed input requirements[2] are available. The code is presently available to all U.S. users directly through BNL. Foreign governments and parties can also obtain this code via agreements between them and the United States. The Federal Republic of Germany has already obtained the code through such an agreement. SSC-L has thus moved from a purely developmental effort into the applications arena.

A major program milestone was reached in November, 1979, when the SSC-P code became operational at BNL. It is now undergoing extensive testing and documentation before official release later in 1980. This code will provide an advanced analytical tool for accident analysis in any pool-type LMFBR. Examples of this type of reactor include EBR-II (the only operating fast breeder reactor in the United States), PHENIX and SUPERPHENIX in France, PFR in the United Kingdom, and others.

A new effort recently added to the SSC program is the development of a version of SSC to be applied to operational transients in LWRs. This version is called SSC-W. Key features will be the ability of SSC-W not only to more accurately predict natural circulation transients, but also to achieve a computational speed of real time (or better) simulation.

Work is continuing in several areas for the SSC-S development effort. The development of models for various aspects important for long term transients is being pursued. These areas include: adequate inclusion of intra- and inter-assembly effects; models for auxiliary/emergency cooling systems; and any additional required numerical techniques.

The SSC Validation program is designed to calibrate and qualify the SSC series of codes by applying them to actual test conditions and comparing predictions with results obtained from the test data. Emphasis is currently being placed on detailed analysis, using SSC-L, of pre-operation and acceptance tests in the Fast Flux Test Facility (FFTF).

Advanced Reactor Safety Evaluation

Analytical support to the NRC Division of Project Management is provided through this program. The technical areas covered include: safety analyses of post-licensing issues for the FFTF; evaluations of reactor licensability issues for candidate reactors in the Nonproliferation Alternative System Assessment Program (NASAP); and assessments of certain special licensing issues.

Two significant accomplishments in the area of containment analysis were the developments of the NACOM[3] and CONAN[4] computer codes for use in FFTF analysis. NACOM is a sodium spray fire thermal analysis code which, unlike previous spray fire models, utilizes first principles modeling for the combustion process. Comparisons have been made with experiments and the agreement is rather good. The CONAN code was developed to provide a detailed analysis of evaporation and condensation of sodium in the containment building following a hypothetical accident. The code was used to test simpler model assumptions in the CACECO code which was used in DOE's safety analysis of FFTF.

Work was initiated on the containment response of the Westinghouse floating nuclear plant to a hypothetical core meltdown in relation to NRC's liquid pathway study. In particular, an analysis of molten core debris penetration into a core ladle composed of MgO was undertaken.

An assessment of the natural circulation decay heat removal capability of FFTF and the associated DOE test program was performed. Particular attention was given to the analysis of existing models in relation to the secondary system test results and the needs for model improvements were identified. An analysis of in-vessel natural circulation in FFTF following a loss of heat sink was performed and progress was made in the determination of the critical heat flux for decay heat conditions (see Fig. 2).

A probabilistic study of the shutdown heat removal system for the NASAP heavy water reactor was performed. Comparative reliability analyses were made with the Clinch River Breeder and the pressurized light water reactor.[5]

Special Studies on Acceptable Risk Criteria

An assessment is being made of the practicality of utilizing risk criteria in the licensing of nuclear power stations. Ramifications and implications of utilizing quantitative risk criteria will also be examined in a broad context. Surveys are being performed to collect and analyze relative risk exposures to society for a broad range of activities. Previously proposed risk criteria are being studied and compared to the Reactor Safety Study and its modifications. This analysis is

reviewing the concept of attainable risks. Statistical approaches are being reviewed in an attempt to include uncertainties into the results along with more current data. The concepts of total risk, core melt, and the risk consequences are investigated as to their applications to the risk criteria.

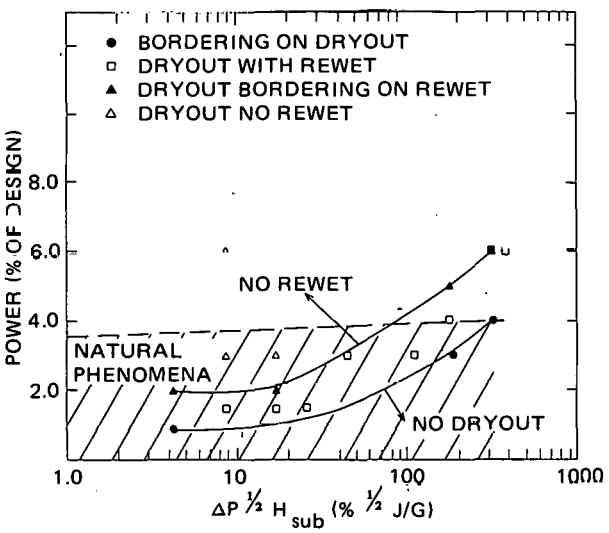

Figure 2. Dryout regimes for the FFTF core determined from the SAS-3D steady-state calculations. On the abscissa the parameter is square root of pressure (in percent of design) across the reactor core times the inlet subcooling enthalpy. The hatched region denotes the range of natural phenomena-induced transient conditions. From K. R. Perkins and R. A. Bari, *Trans. Am. Nucl. Soc.* **33**, 516 (1979).

Human Error Rates

The object of this program is to identify, rank, and characterize the contributions to risk from human actions in the operation of nuclear power stations. In addition, potential areas of the most effective increase in safety by reduction of human error rates will be identified. Future analyses, design changes, and procedure changes necessary to realize the human error rate reductions identified are being explicitly identified.

BNL is categorizing all human errors analyzed in WASH-1400 as reported in current data bases with regard to type of act involved, size of the assessed error rate, and system, accident, and other contextual variables. Each human error rate assessed in WASH-1400 is being reevaluated in light of any new applicable data. BNL is quantitatively ranking the contribution of each human error rate with regard to impact on system unavailability, release category probability, core melt probability, and average risk, through the use of sensitivity studies. Additionally, the Licensing Event Report data file is being utilized to help develop generic human error rates.

A symposium of experts on human factors has been conducted by BNL through IEEE. The detailed transactions are presently being published by IEEE.

Simulator Mode Evaluation and Development

The program is assessing current reactor simulators and, where needed, developing improved engineering models for simulators for the Division of Reactor Safety Research. Emphasis is placed on the capability of simulators to assist nuclear power plant operators in understanding the fundamentals of reactor safety and to serve as a diagnostic tool in controlling reactor transients as well as to provide engineering predictions under severe transient conditions. The project is surveying simulator owners and vendors to determine the capabilities and limitations of hardware and software presently used. Benchmark problems as calculated with reactor safety codes (RELAP-4/MOD7, RETRAN, IRT, TRAC) are being used to determine areas of agreement and disagreement.

At the same time, modeling principles used in the simulator representation are being evaluated. The causes for the differences between simulator and the reactor safety code results are assessed. Important input parameters (geometry, initial conditions, trips, pump curves, transient sequence) for both simulators and reactor safety codes will be studied and significant differences identified.

On the basis of the benchmark comparisons and the modeling evaluation, recommendations on possible improvements to or development of new simulator models will be made. These recommendations could include the use of advanced computer technologies such as hybrid computers, vector processors, and distributed processors.

Operating Reactors — Fire Protection

The program is engaged in various studies on the phenomena of fire propagation, detection, and suppression as related to nuclear safety.

Models are being developed that will standardize the design and NRC review of systems to mitigate the potential impacts of fires on an operating nuclear power station's safe shutdown ability. This task is presently studying fire plume growth, optimum qualification tests for wall penetrations, effects of high pressure-low temperature fire suppressants on electrical equipment, and the capabilities of passive fire suppression systems.

Thermal Hydraulic Development

The Thermal Hydraulic Development Division programs include work related to light water reactors (LWRs) and to liquid metal fast breeder reactors (LMFBRs).

In the LWR-related work, a new program on the independent assessment of the TRAC code, developed at Los Alamos Scientific Laboratory (LASL), was started. The main objective of the BNL work is to apply the code to simulate several separate-effects experiments to assess the basic thermal-hydraulic models used in TRAC. Further model development, if needed, will then proceed.

A number of basic tests, including the steady-state two-phase critical flow tests and the blowdown tests from large pipes and vessels, have been simulated with the TRAC code. The results, although encouraging, do show the areas where further model improvements must be done. Some difficulties have been observed while simulating several other tests. This information has been transmitted to the code developers at LASL for their consideration in the development of the future versions of TRAC.

Experiments were performed in the heat transfer facility (HTF1) which is a general purpose automatically controlled water circulation loop (800 liters per minute flow capability at temperatures and pressures up to 175°C and 1 MPa, with heating and cooling rates up to 0.5 MW). The results obtained allowed the calculation of nonequilibrium vapor generation rates under depressurization conditions, and were compared with analytical predictions as well as advanced code (TRAC) calculations. These nonequilibrium phase change studies have a direct application in the calculation of coolant inventory following a LOCA. A method was also developed to calculate the critical mass flow rates through converging-diverging nozzles with subcooled inlet conditions allowing high degrees of superheat (non-equilibrium) in the converging portion of the nozzles.

The LMFBR experiments are directed towards studies of phenomena related to various aspects of core disruptive accidents. A study of the heat transfer characteristics of volume-boiling pools has been completed. Correlations were developed to describe the rate of heat transfer from boiling fuel-steel mixtures to bounding structures. It has been shown that the heat transfer mechanism is dependent on the boiling flow regime. An experimental system, which incorporates a gamma densitometer apparatus, has been completed to study the hydrodynamic dispersion characteristics of boiling fuel-steel mixtures using simulant materials. Preliminary results were obtained, substantiating the dependence of the dispersion behavior on the flow regime. Work was initiated related to core disruptive accident energetics. Entrainment of sodium into the expanding two-phase bubble by the mechanism of Taylor instability growth was studied. Analytical studies showed that the presence of a heavy liquid phase in the bubble tends to stabilize the growth of interfacial disturbances. This finding reduces the likelihood of sodium entrainment by Taylor instability growth. A technology assessment report was completed, which reviews the thermal hydraulic technology pertinent to the transition phase of a core disruptive accident.

High Temperature Gas Cooled Reactor Safety Evaluation

The High Temperature Gas Cooled Reactor (HTGR) is a thermal reactor with a ceramic fuel (oxide or carbide) incorporated in a graphite moderator cooled by helium at pressures of the order of 50 kg/cm^2. The nature of the core materials permits exit coolant temperatures of the order of 800°C. The heat can be utilized either in conventional steam generator-turbine cycles or in direct closed cycle gas turbines for electricity or directly as input to chemical processes such as syn-fuel production. The effort is directed to provide research support to the NRC in its evaluation of the safety of HTGR systems.

The long term effect of traces of impurities in the coolant helium on the graphite and metallic components of the reactor internals is being in-

vestigated to determine mechanisms of possible structural degradation. Experiments in the Helium Impurities Loop are helping to clarify the kinetics and equilibrium reaction taking place between the reactor internal metals and the trace impurities in the helium. The High Temperature Facility is being used to understand the mechanisms of transport of fission products through graphite at the high temperatures that could conceivably be reached under severe accident conditions.

Corrosion Science

The department has research programs in the Corrosion Science area with DOE and NRC, as well as Technical Assistance programs for three divisions of NRC. For the DOE Division of Basic Energy Sciences, the group has a research program on the mechanisms of intergranular stress corrosion cracking of iron- and nickel-base alloys, which includes studies of segregations within the material, and the electrochemistry of the attack, using unique approaches developed at BNL. A recent development permits remote detection of localized surface inhomogeneities that can lead to corrosion by an x-y scan of a square wave ac probe. This technique is uniquely suited to studying high temperature corrosion processes. Figure 3 indicates the signals obtained from an ac scan of a polished surface of a stainless steel specimen into which an "x" of silver had been embedded. For the DOE Division of Geothermal Energy, BNL is developing alloys with improved resistance to pitting attack by geothermal brines. For the NRC Division of Engineering Standards, Operating Reactors and Systems Safety, BNL performs technical assistance on a broad range of problems of corrosion and coolant chemistry in water-cooled nuclear power reactors, and of evaluating inservice inspection programs for detecting this corrosion. This assistance includes reviews of generic problems, specific licensing actions, and has included serving as technical witnesses for the NRC staff. For the NRC Division of Reactor Safety Research, BNL is experimentally studying the factors causing stress corrosion cracking of Inconel 600 steam generator tubing in PWR environments.

Nuclear Waste Management

Brookhaven has taken on a broad program of support to NRC in the area of radioactive waste management. The technical support provided will address particularly the storage and disposal of high level (HLW) and transuranic wastes (TRU), long term storage of spent fuel, and research being conducted in all areas of waste management. BNL is charged with assisting NRC in development of criteria and standards for isolation of nuclear waste, particularly those

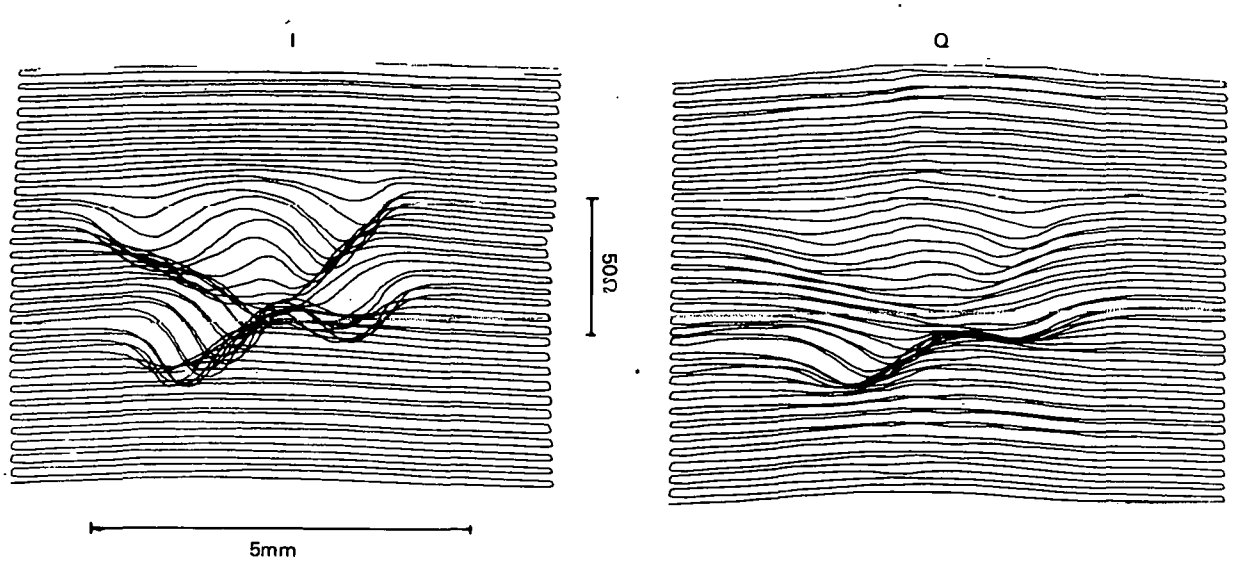

Figure 3. The in-phase, I, and quadrature, Q, impedances for a raster scan of a test type 304 stainless steel with a silver solder cross imbedded in the surface. Measuring square wave frequency, 1000 Hz.

given in the document 10CFR60 such as the requirements that:

1. there shall be zero release of radioactivity from HLW repositories to the biosphere in 1000 years, and
2. release rate after 1000 years shall be no greater than 1 part in 10^5 per year.

In September, 1979, a new division was formed in BNL's Department of Nuclear Energy to carry out these tasks. The department's ongoing experimental program in management of low level waste will continue within this new Division of Nuclear Waste Management. The division's support role is expected to grow considerably and it is also expected that a sizable experimental program will be initiated in the near future in the area of high level waste management.

The experimental program in low level waste management continues the investigation of leaching and properties of solid radioactive wastes and waste containers, and the study of commercial low level radioactive waste disposal sites.

Property determinations were conducted on simulated waste forms of types currently produced at nuclear reactors. Data were developed to determine envelopes of process parameters within which there is reasonable assurance that satisfactory solidification will occur. Such parameters include waste to binder ratio, pH, and amount and type of chemical additives. These data will be compared to data obtained from solidified reactor waste, and will provide the technical bases for establishing criteria for the safe disposal of solidified radioactive wastes.

An objective of the commercial disposal site study is to describe the physical, chemical, and biological properties of the geochemical system that control the movement of radionuclides.

Water samples from the Maxey Flats, Kentucky, West Valley, New York, Sheffield, Illinois, and Barnwell, South Carolina disposal sites, obtained using the anoxic procedures developed to eliminate problems associated with air-exposed trench waters, were analyzed for inorganic, organic, radiochemical, and bacterial constituents.

Micro-organisms have been identified as potential contributors to the migration of radionuclides. Aerobic and anaerobic bacteria isolated from the trench waters grow under anoxic conditions in the trenches and are not adversely affected by the organic and radioactive wastes buried there.

Numerous organic compounds originating from the buried cellulosic materials, scintillation liquids, solvents, and decontamination fluids, some of which have the potential for chelation of radionuclides, were measured. Sorption distribution coefficient (K_d) studies in progress, under conditions simulating the trench environment, will aid in the prediction of movement of radionuclides at the sites.

Structural Analysis

The Structural Analysis Group provides assistance to the NRC and the DOE in the areas of seismic analysis, structural behavior, and stress analysis. Programs in these areas are under way as part of other research programs and as separately funded projects.

A listing of the current programs includes the following: Piping Benchmark Development, Load and Response Combination Evaluation of Mark II and III Concrete Containment Structures, Seismic Criteria Documentation, Concurrent Peak Response Evaluations, Soil Structure Interaction Studies, and Steam Generator Tube Integrity Studies.

In the Piping Benchmark Program, the Group is developing benchmark programs which are used by NRC to validate the computational methods used by nuclear systems suppliers in qualifying nuclear plants. Under the Concurrent Peak Response and Concrete Containment Structures programs, the Group is assisting NRC in the development and assessment of criteria for the combination of dynamic responses, such as seismic, chug, water hammer, and relief valve slam. Under the Soil Structures and Tube Integrity programs, the Group is developing new computer methods. For the former, this development will provide NRC with simplified computer methods for soil structure evaluations, while for the latter, it will provide NRC with an independent capability to evaluate the integrity of tubes and nozzles undergoing inelastic deformations. Lastly, under the Seismic Criteria Documentation program, the Group is assisting NRC in the collection and compilation of seismic data for all licensed nuclear plants.

NATIONAL NUCLEAR DATA CENTER

The National Nuclear Data Center (NNDC), provides data center services to the entire low energy nuclear science community. In addition to the existing neutron physics information service, information on charged particle reactions, nuclear structure, and decay data is available on request.

The IAEA Nuclear Data Section coordinates an international effort in nuclear structure and decay data (NSDD). A network of NSDD evaluation centers has been set up within the United States, and is called the U.S. Nuclear Data Network (USNDN). The USNDN is coordinated by the NNDC which also serves as the United States representative to the international network. The Center contributes mass chain evaluations to the Nuclear Data Sheets.

The NNDC acts as the secretariat for the Panel of Reference Nuclear Data (formed October, 1976) and hosts the annual meeting of the Panel. The Panel acts as an interface between the scientific community and nuclear data centers and funding agencies. It advises the centers and agencies of the nuclear data needs of the community and informs the community through the member societies of the data available from the centers. The minutes of the latest Panel (May 1979) are available as a BNL Report. One outgrowth of this has been the annual publication of "A Source List of Nuclear Data Bibliographies, Compilations and Evaluations" compiled, prepared, and disseminated by the NNDC.

The Center released the 3rd edition of a bibliography of publications of integral charged particle reaction data, and is continuing its participation in the production of CINDA, a neutron physics bibliography. A review of the CINDA file entries and the addition of the index to the available experimental data in the file has been completed and published covering the years 1935 to 1977.

A file of requests for measurements is maintained at the Center to support the DOE Nuclear Data Committee (DOE/NDC) reviews of such material and a BNL report, the "U.S. Compilations of Requests for Nuclear Data April 1979," has been issued.

Forty-two isotopes including some structural materials and rare earths were evaluated, submitted, and accepted for a national reference system for nuclear data entitled Evaluated Nuclear Data File (ENDF/B-V) and published early in 1979.

National and international commitments for the past ten years necessitated the use of a dedicated computer system at the Center. The Center's expanded responsibilities over the past five years required an upgrade of that computer system. The upgrade represents an approximate increase of 7:1 from the original DEC System-10 KA-10 processor.

NUCLEAR MATERIALS SAFEGUARDS

The function of the Technical Support Organization (TSO) is to provide technical assistance to DOE and NRC in their development of policies and procedures in response to perceived threats of nuclear facility sabotage and nuclear material theft or diversion. Internationally, concern centers about the clandestine production, or national diversion, of material for use in nuclear weapons production (proliferation); domestically, safeguards are aimed at preventing unauthorized possession or use of nuclear materials, and the sabotage of nuclear facilities.

Major emphasis was placed by the United States these past three years on the need to prevent or delay further nuclear proliferation. The TSO role, under DOE sponsorship, involved significant participation in the Nuclear Alternative Systems Assessment Program (NASAP) and in the International Nuclear Fuel Cycle Evaluation (INFCE). Typical TSO contributions included extensive studies of the safeguards aspects of the thorium fuel cycle, the various techniques for the clandestine production of weapons material, and heavy water and tritium accountability problems. TSO personnel were charged by DOE with the responsibility of preparing or reviewing the safeguards portions of U. S. contributions to the various INFCE working groups and with reviewing and commenting upon papers produced by other nationals.

TSO has been particularly active in the past year in helping DOE prepare for the IAEA inspection of U.S. facilities under the "President's Offer" and in supplying representation on various IAEA working groups related to reprocessing, enrichment, safeguards effectiveness, etc.

DOE-funded domestic safeguards matters involving TSO over the past year have included a

comprehensive review of vaults; instrumentation development, procurement, and placement in DOE field offices; and general program and proposal assessment and review.

Two major efforts are under way for the Office of Nuclear Material Safety and Safeguards (NMSS): the preparation of a series of handbooks to aid licensees in the preparation of submissions required under the "President's Offer," and to aid NRC in reviewing these submissions; and a detailed consideration of safeguards-related regulatory problems which might arise if any of the fuel cycles projected by the NASAP/INFCE studies were to be implemented. Continuing instrumentation and consultant support is supplied to Region I of the NRC Office of Inspection and Enforcement.

A number of continuing projects have been assigned to TSO by the International Safeguards Project Office. Project topics include non-destructive assay instrument development, safeguards effectiveness evaluation, and the preparation of guides and manuals for use by foreign countries in the organization of their safeguards systems.

INTERNATIONAL SAFEGUARDS PROJECT OFFICE

The U. S. continues its strong support of the International Atomic Energy Agency in improving the effectiveness of international safeguards. The support program, under technical management of the International Safeguards Project Office (ISPO), is entering its fourth year.

The U. S. Program of Technical Assistance to IAEA Safeguards (POTAS) has provided for the development and transfer to IAEA of 34 types of equipment. This equipment has included assay instrumentation for verification of nuclear material, seals, picture-taking systems, and other equipment for verification that material had remained in place between inspections, and equipment for information processing by the IAEA safeguards staff.

Training has been provided to members of the IAEA staff and to safeguards personnel of member states in courses designed to increase ability of IAEA staff to perform their assigned tasks. Analytical studies have been carried out on 10 aspects of the IAEA safeguards by technical experts with a view to assessing and improving potential IAEA effectiveness.

Perhaps the most effective form of assistance has been to provide a total of 28 cost-free experts for extended service under contract to the IAEA, mostly in the staff of the Division of Development and Technical Support. The presence and participation of these experts has greatly increased the ability of the entire IAEA safeguards staff to absorb and use technical improvements. IAEA recently requested 56 new tasks that will be started in CY 1980 or early FY 1981.

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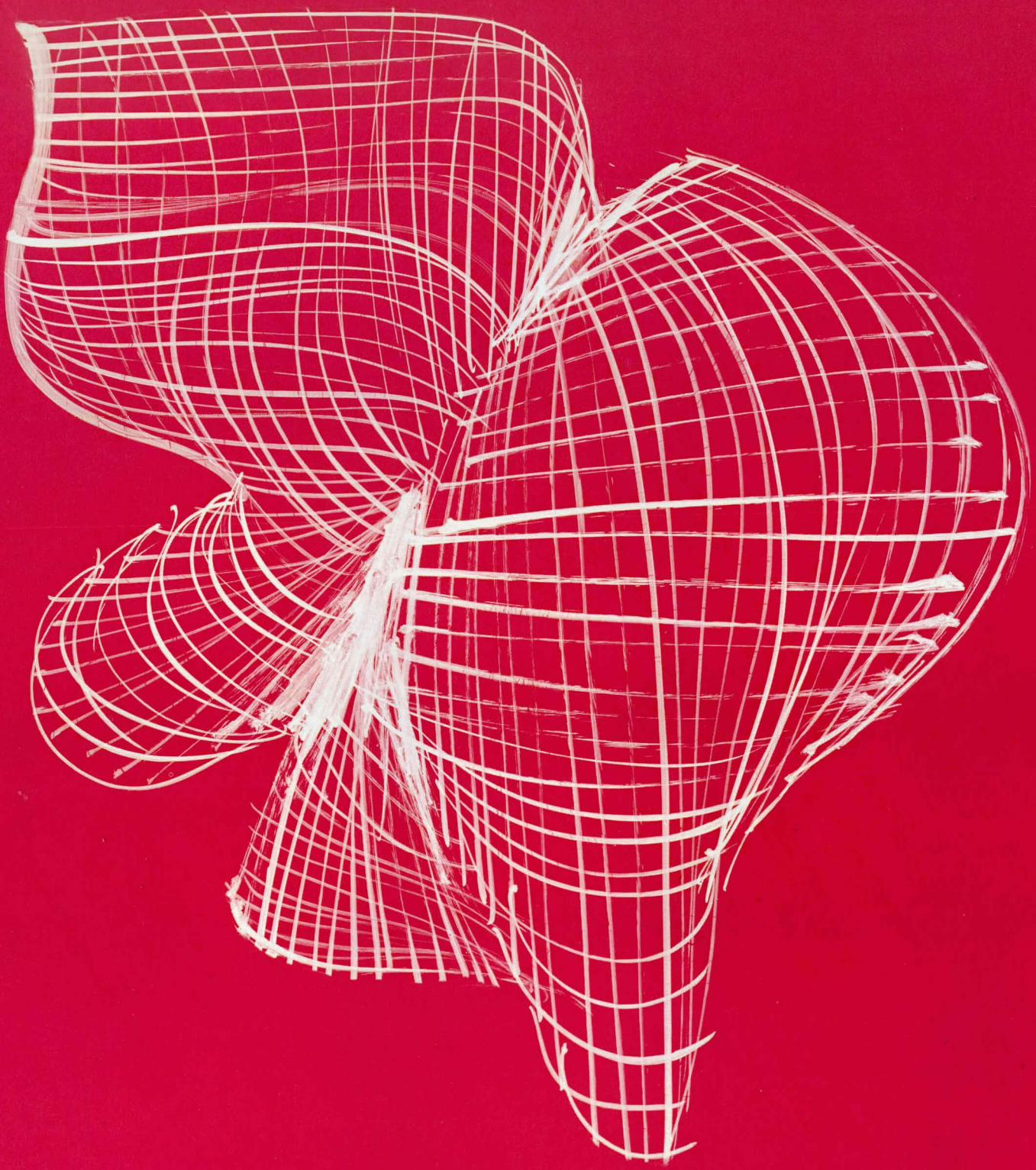
Support Activities

Applied Mathematics Department

Instrumentation Division

Reactor Division

Safety and Environmental Protection Division



Applied Mathematics Department

INTRODUCTION

The Applied Mathematics Department has three missions: to carry out research in the applied mathematical sciences, to provide consultation and professional services in the application of computational, statistical, and mathematical techniques, and to operate and maintain an extensive scientific computational facility.

RESEARCH IN MATHEMATICS

The research in mathematics is concerned with the development and application of analytical and numerical techniques for extracting information from complex mathematical equations arising in energy-related research investigations. The emphasis is on techniques which, although they may be prompted by, and developed in conjunction with, a specific research question, can be expected to have a broad range of application across a number of different programs.

Partial Differential Equations

The major thrust of the mathematical research is on the solution of partial differential equations. Such equations arise in almost every attempt to model theoretically the behavior of a physical object or system. Because of their complexity, approximate numerical techniques must be used to solve them. The main purpose of the research in this area is to understand the nature and reliability of existing approximate methods, and to develop new methods which will reduce the computational effort required to obtain acceptably accurate solutions. Variational techniques, spectral methods, finite element methods, and Fast Fourier Transforms are among the techniques used, while the applications include reactor simulation, atmospheric modeling, wave propagation studies, and the computation of magnetic fields.

The main emphasis of this work at Brookhaven concerns the solution of important classes of partial differential equations with applications in a wide variety of energy related areas. This involves (1) analytic investigations of the differential equations and their solutions, (2) the development, analysis, and testing of various algorithms for approximately solving these differential equations, and (3) the application of these results to problems in other areas of research.

Evolution equations constitute an important class of partial differential equations whose solutions require a variety of sophisticated numerical techniques. Spectral methods have recently been employed quite successfully in connection with such problems. These methods have been analyzed rigorously at BNL, and error bounds established for various classes of evolution equations, including advection equations (of importance in meteorology and pollution modeling) and non-linear models of dispersive waves. Due in large part to the Fast Fourier Transform, these methods may be implemented very efficiently. In addition to the analysis of spectral methods, computer codes were developed at BNL to confirm their efficiency and accuracy.

High order time stepping methods for solving nonlinear parabolic evolution equations are also being developed, analyzed, and implemented at BNL (in joint work with a collaborator at Cornell University). These methods have been applied to a nonlinear Schroedinger equation which arises in the modeling of laser propagation. An important feature of this new method is that it requires only the solution of a fixed matrix equation per time step.

The solution of elliptic boundary value problems is another important area of investigation at BNL. Finite element and related variational methods are an important tool in obtaining approximate solutions for such problems. The development and analysis of finite element methods and their application to various boundary value problems constitutes an important part of this work. Some of the results of this research include error estimates for conforming and non-conforming finite element methods, the effect of numerical integration on the computed solution and the application of finite element

methods to problems in unbounded regions. Another important research area in connection with elliptic problems is the development of efficient, accurate methods for solving the large systems of linear equations resulting from discretizing the given problem. As part of the collaborative work with Cornell, various "fast elliptic solvers" are currently being investigated. These include pre-conditioned conjugate gradient techniques, alternating direction implicit methods, and fast capacitance methods.

The work on finite element type methods has been and is currently being applied to the study of various problems in wave propagation. Some of this work is in collaboration with the Courant Institute of Mathematical Sciences. The scattering of acoustic or electromagnetic waves is usually described by the Helmholtz equation in an unbounded domain, with an appropriate radiation condition at infinity. A new finite element method has been developed, analyzed, and tested for solving problems of this type. It has resulted in a drastic reduction in the number of linear equations to be solved. The computation of magnetic fields in two and three dimensions is another area in which the research on elliptic boundary value problems may have an important impact. Fast Fourier Transform ideas and iterative methods are being explored in an attempt to reduce storage and run time for a widely used computer code based on any integral equation formulation of this problem. A finite element method for directly solving the boundary value problem is also being considered.

Multiple fluid flow calculations have important applications in connection with the physical modeling of reactors. Much of this work involves interactions with various engineering groups, both at BNL and elsewhere. As a result of this research, it has been demonstrated that a two-fluid thermal hydraulics calculation method is effective in improving the numerical treatment of heat transfer and of interfacial drag. Methods are currently being investigated for overcoming the convective time step limit using fractional step methods. Since modeling of multiple fluid flow has led to mathematically ill-posed problems, an effort is being made to apply the mathematically ill-posed problems to such models. Finally, it is intended to investigate computational methods for more complicated models that involve more than two fluids or models that include the effects of two-phase turbulent mixing.

Image Reconstruction

Image reconstruction (also called "computerized tomography" and other names) is, in general terms, concerned with estimating functions from their integrals over lines or planes in space. This is a topic with a broad range of multidisciplinary applications, and one which has been subject to intensive development since the advent of EMI's first computerized axial tomography (CAT) scanner several years ago. Brookhaven has a long-standing interest in the subject dating from its development (in the Medical Department and Instrumentation Division) of the first positron ring scanner in the early 1960s, and in 1974 was the host of the first international multidisciplinary meeting to have been devoted to image reconstruction. Applied Mathematics Department work in this area has recently been concerned with such problems as (1) establishing general mathematical features, such as the existence of a singular-value decomposition with certain spectral properties, for a particular class of image reconstruction problems; (2) finding consistency conditions for the so-called "attenuated" Radon transform which arises in single-photon emission tomography; (3) reconstruction from projections taken from an arbitrary set of directions; and (4) reconstruction from planar integrals as occurs for example in nuclear magnetic resonance zeugmatography. Collaborative arrangements have been established with investigators at LBL's Donner Lab, the U.C. Berkeley Mathematics Department, Ames Laboratory, and the State University of New York at Stony Brook and at Buffalo. Another important aspect of AMD work within the area involves collaborative and consultative arrangements with pertinent programs elsewhere at Brookhaven, especially within the Medical Department.

MATHEMATICAL PROGRAMMING

The mathematical programming work is mainly concerned with optimization studies which arise in energy systems analysis. The purpose of the work in these areas is to gain better understanding of existing algorithms and to develop new ones which will allow more complex problems to be attacked with the existing com-

puter technology. These algorithms are developed into tested and documented software packages.

Large-Scale Linear Programming

The most promising decomposition algorithms have been implemented using state-of-the-art, modular linear programming software (IBM's MPSX/370) as building blocks. The capability of the latter as a tool in systems analysis and optimization is thus extended many fold.

Dynamic Networks With Congestion

This problem concerns dynamic flow over a network where congestion is modelled explicitly in the flow equations. Theoretical results were obtained which led to a very efficient method to solve this apparently difficult problem.

RESEARCH IN STATISTICAL METHODS

The research in statistical methods is concerned with the mathematics underlying the process of confrontation between measurement or observation, on the one hand, and a theory, model, or expectation, on the other. It involves questions of experimental design as well as those of data analysis and estimation. The mathematical tools to implement objectives in design or analysis do not directly depend on the field of application, and a considerable portion of the work carried out lies in the general area of statistical inference. At the same time, particular fields may raise statistical questions with a specialized focus.

Close cooperation exists with research programs in and statistical work supported by the environmental programs of DOE. The methods and results, however, have a broader application than these programs. Reliability and risk analysis represents another closely related area of specialized statistical concern, which has impact on biostatistics as well as more general questions of public policy.

Sequential Experimentation and Decision Theory

A very practical method was developed to help decision makers evaluate their preferences among conflicting objectives. The HOPE method is simple to use, easy to understand and relies on only existing linear programming techniques. It has the additional advantage of providing a holistic view of the alternatives from the outset.

An asymptotically optimal sequential procedure was developed for selecting the best of several unknown normal populations with common variance. The precise effect of changes in the designed control parameters in the procedure on the performance of the procedure was asymptotically expressed.

Robust Statistical Procedures

A general method of deriving robust test procedures for composite statistical hypotheses was developed along with a general existence proof for $\sqrt{n}$-consistent and resistant estimators. The one-sample robust t-test and F-test were obtained, and proved to be highly efficient for testing the location and scale of normals.

Reliability and Risk Assessment

New aspects of the empirical Bayes method in statistics were examined. Emphasis was on the quantitative prediction of future performance of those subgroups of a population that have done either well or badly in the past, without making specific assumptions on how attributes are distributed in the population. The theory was worked out for distributions of the binomial, exponential, Poisson, and geometric families.

A model for low dose risk assessment using the notion of a multihit theory of carcinogenesis was developed and explored. Statistical procedures for estimating the parameters of the model and for doing the low dose extrapolation were developed.

A potentially hazardous environment implies certain consequences in public risk. Theoretical results were obtained giving conditions when social preference for equitable distribution of risk prevails.

Rate of Return Analysis

Since 1954, the federal government has been leasing tracts in the outer continental shelf (OCS) for the purposes of exploration, development, and production of petroleum. A lease is granted on the basis of cash bonuses offered to the government at leasing auctions conducted by the Department of Interior. In addition to the cash bonus, the government receives from a leaseholder rent and royalty on the revenue derived from the tracts. Through 1978, OCS oil

and gas leases have produced direct revenue of over $28 billion to the federal government.

In order to properly discharge its responsibilities of OCS management as stipulated in the OCS Lands Act of 1953 as amended in 1978, the Department of Interior, through the Conservation Division of the U. S. Geological Survey, is concerned with certain questions which may have important implications for policies related to OCS gas and oil reserves. In 1979, the research staff of the Applied Mathematics Department started work to provide technical support on mathematical problems connected with some of these policy-related issues.

Currently work is being done to obtain some insight into the question of whether or not the government is receiving fair market value for its OCS lease. This question invariably leads to the question of profitability, and various means of estimating the rate of return to the petroleum industry from OCS leases are being studied.

RESEARCH IN COMPUTER SCIENCE

This computer science research deals with the investigation of distributed processing techniques and their application to applied mathematics problems. This work complements developments elsewhere aimed at increasing computational power by improving algorithms for sequential computing or by the development of parallel processors. The problems which may be amenable to this approach are some of those which involve computationally simple sub-problems coupled loosely in a manner which may be very complicated to model on a sequential machine but easy to implement as connections between independent processors for each subsystem. Reactor safety modeling calculations seem to have these characteristics and provide a specific application focus for this work, although positive results have much broader implications. The work involves both algorithmic development and the empirical study of the operating characteristics of such sets of coupled processors. Some work also was associated with providing Laboratory participation in the ARPANET.

Distributed Computing

The economics of computing is in a period of rapid change. The technology of Large Scale Integration (LSI) and Very Large Scale Integration (VLSI) is dramatically reducing the costs of low and medium speed computer hardware, while the fastest computers remain relatively expensive. This has led to an interest in building high performance systems from large groups of lower performance computers. The programming of such systems is very different from the traditional manner of programming single computer systems. A large computation must be decomposed into many smaller computations that may be simultaneously executed. One of the areas of research has been into techniques of control and synchronization of these multiple, parallel computations. Another area of research has been the exploration of alternative architectures for developing special purpose computers. For example, in order to build a control room simulator for a nuclear reactor, a very large set of equations must be solved in real time. If a computer especially designed for this task could be constructed from general purpose building blocks, then the accuracy of the simulation could be improved for a realistic cost.

QUEUEING NETWORK MODELS

In recent years, the growth in complexity of large scientific computer configurations has outpaced the development of the theory showing the relationships between the workload of the computing facilities and their communication and processing capacities. As a result these networks are susceptible to both traffic bottlenecks and poor utilization of expensive computing devices.

Two studies have been undertaken to develop the conceptual tools for the analysis of workload distribution in these complex systems. The first is the study of queueing networks. Each computer or communications device is represented as a queue — a theoretical component whose statistical output characteristics are described in terms of its input and its internal policies. But the results obtained from studies of individual queues cannot always be applied in networks, because of the overwhelming complexity of the most general interactions among queues. The results already obtained in the study of queueing networks characterize the conditions under which solutions for arbitrary and complex network configurations are obtainable.

The second study involves the analysis of the technique of discrete-event simulation, a widely-used computer programming method for understanding complex systems. Some techniques of queueing theory were used to reduce complex simulation models to well-understand mathematical models, which then served as validations of the more complex cases, and as guides for further investigation.

RESEARCH COMPUTING FACILITY

Digital computers are permeating almost every area of human endeavor, and are fast becoming household tools. The research scientist has utilized computers for many decades. In fact, access to adequate and responsive computing resources is one of the most essential ingredients of an effective research environment in many fields.

The Central Scientific Computing Facility at Brookhaven has the responsibility of providing that access. In its present configuration the computational power is provided by three large scale computer systems, a CDC 7600 and two CDC 6600s amalgamated into a unified system which, together with a variety of peripheral devices, provides a broad range of capabilities. Access to the system is by hardwired remote batch terminals distributed around the site and by telephone-connected terminals for most of the interactive use.

The provision of more and better high level software, such as the packages needed for database management and graphics, has been an increasing emphasis. Assistance for those who use the computers, either through advice and consultation, development of new capabilities, or the actual carrying out of analytical or programming tasks for the research programs, has become a major component of the CSCF activities.

The direction of computing in research now points more and more towards "distributed computing". In this mode the tightly coupled main computers of the present facility evolve into a more loosely coupled local network with smaller computers at many remote locations which have the ability to communicate with the central facility. The rapid deflation of the cost of computers achieved through new technological developments has made it economically feasible for small but powerful computers to be employed at the immediate site of scientific experiments, both as control devices and data collection and processing systems. Interconnection of these computers with the central facility will enable them to transmit data needed in computations which can be handled only with the extended resources of the central facility, and receive the results of such processing.

SELECTED PUBLICATIONS

C.I. GOLDSTEIN. Numerical Methods for Helmholtz Type Equations in Unbounded Regions. *Proc. Conf. on Math. Methods and Applications of Scattering Theory, Washington, DC, May 1979,* BNL 26543.

J.K. HO, E. LOUTE, Y. SMEERS, AND E. VAN DER VOORT. The Use of Decomposition Techniques for Large-scale Linear Programming Energy Models. ENERGY POLICY'S Special Issue on Energy Models for the European Community, 1979, pp. 94-101.

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C.S. KAO. Asymptotic Properties of Robust Estimators of Maximum-Likelihood Type with Order Statistics. Bulletin of the Inst. of Math, Academia Sinica, **7**, (1) 99-112 (1979).

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A.S. NOETZEL. The Product Form Queueing Network Model in Computer Systems Analysis. *Information Linkage Between Applied Mathematics and Industry,* Peter C.C. Wang, Editor, Academic Press, NY, pp. 599-608, 1979.

APPLIED MATHEMATICS

R.F. Peierls — Department Chairman

G.H. Campbell Computer Science: Distributed computing.

C. Goldstein, H.B. Stewart, P. Wang Partial Differential Equations: Evolution equations, high order stepping methods, elliptic boundary value problems, finite element type methods, multiple fluid flow calculations.

J. Ho Optimization and Decision Science: Large scale linear programming, dynamic networks with congestion, multiple criteria optimization, public risk, and individual values.

S. Kao Statistics: Robust test procedures, sequential procedures, empirical Bayes method, and risk analysis.

R.B. Marr Image Reconstruction: Computerized tomography.

A.S. Noetzel Computer Science: Queueing network models.

Y. Shimamoto Economic Rate of Return Analysis.

Instrumentation Division

The Instrumentation Division engages in research and development on recognized problems in scientific instrumentation that are important to the long-term goals of the Laboratory and the Department of Energy. The Division provides consultation services in the areas of instrument specification and selection to other departments of the Laboratory. The Division also designs and constructs some of the instruments required by the departments in the course of their research. These instruments are typically of such an advanced design that they are not commercially available. In addition, the Division provides services in electron microscopy, vacuum technology, printed circuit board fabrication, scientific instrument repair, and computer maintenance.

Members of the Division also collaborate in experiments at BNL and other laboratories when they can contribute significantly to the advance of scientific research with new devices, methods, and techniques developed at BNL.

The principal areas of research activity are the detection of nuclear particles and of radiation with semiconductors and gaseous and liquid detectors; processing of signals from detectors; low-noise and other special electronic circuits; systems for acquiring data and control of scientific experiments; and application of nuclear and atomic techniques in elemental analysis and other fields. Some of the more important recent results are described below.

RADIATION DETECTION AND SIGNAL PROCESSING

High Resolution Ion Chambers

The pair of ion chambers (Fig. 1) designed for an EXAFS experiment which underwent first tests in the spring of 1979 was used in an EXAFS experiment at SLAC in the summer of the same year. A large dynamic range ($10^2 \ldots 10^{10}$ pho-

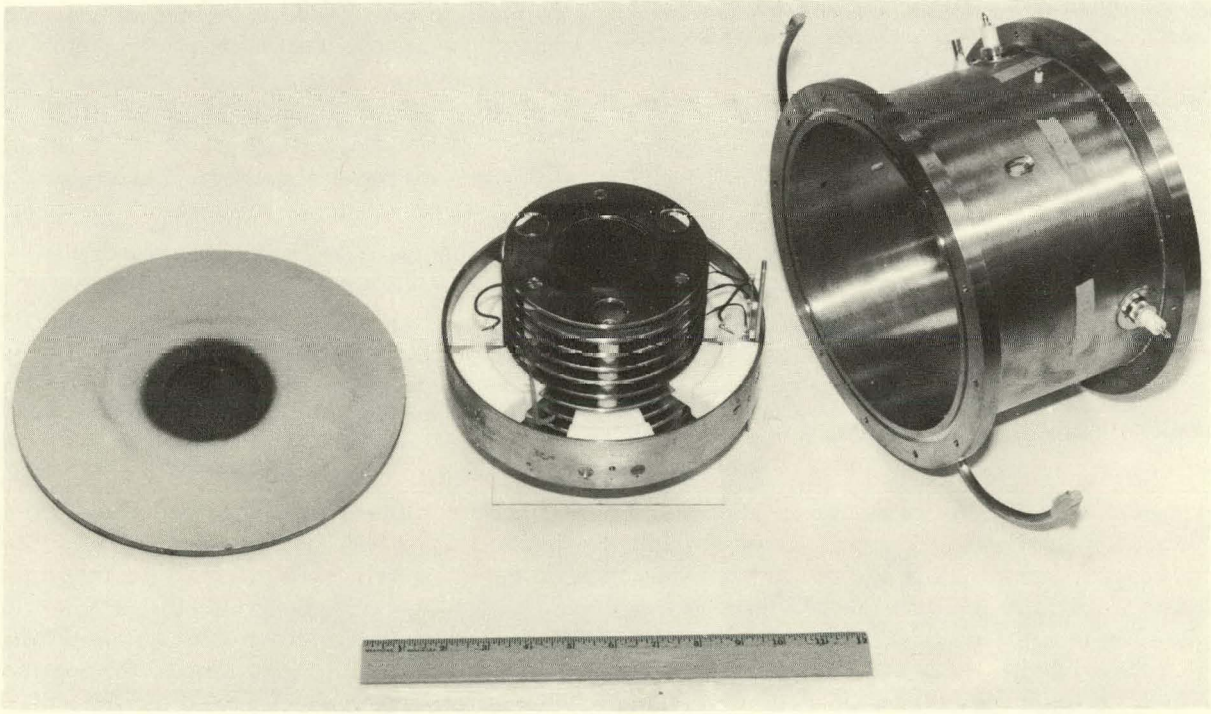

Figure 1. High linearity ion chamber developed for use in EXAFS experiments with synchrotron light.

tons/sec), high linearity (deviations $< 5 \times 10^{-3}$), and extremely flat plateau were observed. In this range, the observed current fluctuation was given by the quantum noise if a radioactive source was used. Large fluctuations have been found in the EXAFS measurement and further investigation is planned to decide whether it is due to the EXAFS or caused by the monochromator/synchrotron light source. The low noise and high linearity of the system will enable the recording of high quality EXAFS data with conventional x-ray generators (rotating anodes).

Microstructure of Primary Ionization and Its Application for Identification of Particles at Relativistic Velocities

The theoretically predicted increase of the number of primary ionization collisions with the increase of γ ("relativistic rise") has been verified experimentally using the arrival time distribution of the "first" cluster in a proportional counter. The agreement between theory and experiment is satisfactory.

The measurement of this number for a single track would give much improved particle identification compared to the "classical" measurement of the relativistic rise of the total ionization. The time expansion chamber, a special type of drift chamber, resolves single clusters as close as 100 μm from each other and permits the measurement of the number of clusters with relatively small losses. First measurements at the AGS (BNL) and at the SPS (CERN) showed only half the expected relativistic rise. Although this already results in a performance for particle separation which is as good as the standard method, further measurements are under way either to improve the result or reveal interesting new aspects of the primary ionization.

Drift Chambers With High Position Resolution

With increasing energy of the present and future accelerators for high energy physics, the measurements of momenta become increasingly difficult. Therefore, a program has been started to investigate the ultimate precision of momentum measurement by using drift chambers in a magnetic field.

The position resolution of drift chambers achieved up to now cannot be explained by the conventional assumption that diffusion of the drifting electrons, statistics of the primary ionization, and fluctuations in the time measurement process of the signal are the principal contributions. Although the measured resolution in small test setups is better than expected from simple calculations based on the above assumptions, it does not mean that this is already the ultimate resolution achievable. In addition, the basic understanding of drift chamber resolution is necessary in order to optimize the parameters for the construction and operation of large detectors. Special chambers have been built or are under construction to measure diffusion signal formation and primary ionization fluctuations separately.

It has already been found that diffusion in a drift chamber mixture is smaller than predicted from the literature, thus following the observed effect in some pure gases that the diffusion parallel to the electrical field is generally different from its value perpendicular to it (the later is normally quoted in the literature). The pulse height distribution and the frequency of single ionization clusters could be determined, which will provide the necessary data to understand the measured resolution of drift chambers. More measurements for various gases and the influence of a magnetic field are under way. Another line of research covers the necessary calibration and monitoring systems for operation of large detectors with the required high precision.

Lifetime of Proportional Wire Chambers Under Intense Radiation

The intrinsic high rate capabilities of multiwire proportional counters are usually not in equilibrium with the normal lifetime under such conditions. After a relatively short time, deposits are found on the anode and cathode impairing the gas amplification. Previously we had found that certain gases in very clean counters show much improved lifetime. In the meantime, the effects of different types of ionization (minimum ionizing or x-rays) on the aging have been observed, as well as the effect of the rate of gas flow. New measurements are under way (lifetime measurements unfortunately require some time) and hopefully will confirm these effects and lead to a better understanding of the above mentioned observations.

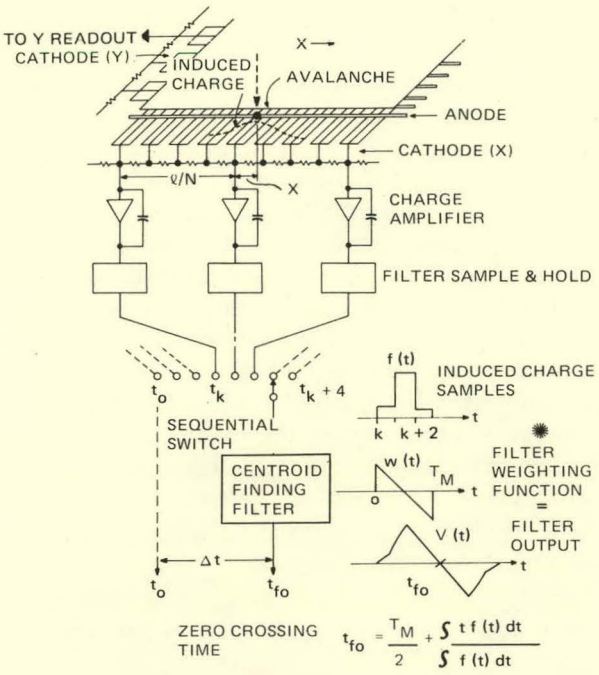

Figure 2. Centroid finding by convolution. Preamplifier outputs from subdivided resistive chain (or a continuous resistive sheet) are switched sequentially into the centroid finding filter. Noise from three outputs only enters the result. Zero crossing time t_{fo} is a continuous linear function of the charge (centroid) position x over the whole detector.

New Centroid Finding Method for Position-Sensitive Detectors

With increasing demands on the position resolution and on the event rates, position readout methods represent one of the most vital areas of detector research and development. The emphasis in the work here has been on the investigation of various methods for determination of the centroid of the induced charge and of the light in ionization and scintillation detectors.

A new method for centroid determination (Fig. 2) for all detectors where the signal charge is collected or induced on strips or wires, or on subdivided resistive electrodes, has been developed. The centroid of charge is determined by convolution of the sequentially switched outputs from these subdivisions or from the strips with a linear centroid finding filter. The position line width is inversely proportional to $N^{3/2}$, where N is the number of subdivisions. This method allows the use of an arbitrary number of amplifiers (detector subdivisions) as determined by the position resolution and by the signal charge. The main properties of this method are a small required signal charge (reduced avalanche size), a short time required for centroid determination, and a high absolute position accuracy. For example, an absolute position error of less than ± 80 μm has been measured on a 20 × 20 cm² detector which corresponds to an integral nonlinearity of $\sim 4 \times 10^{-4}$.

Immediate applications of this method are for neutron and x-ray position-sensitive detectors which are under development for use at the HFBR (small angle scattering facility for solid state physics) and at the NSLS (small angle scattering facility for biology). Further applications will be with microchannel plate multipliers and with semiconductor detectors.

Position-Sensitive X-ray Detectors

An R&D program on x-ray detectors was started in response to the forthcoming needs at the NSLS where x-ray beams will be used for research on crystal and molecular structures in biology, solid state physics, and chemistry.

For an efficient utilization of the capabilities of the NSLS, the appropriate position-sensitive x-ray photon counting detectors should have properties exceeding the present state of the art, in particular, very high spatial resolution at extreme counting rates. This is required in dynamic (time resolved) studies, e.g., muscle cell contractions where diffraction patterns may have to be obtained in a few milliseconds.

Experimental investigations made here with small (2 × 6 cm²) multiwire proportional chambers made for such purposes indicate that a spatial resolution along the anode wires of 100-150 μm could be obtained under total x-ray fluxes of $\sim 10^6$ photons/sec without significant deterioration of the spatial resolution or a shift in the position of spectra. The data rate was limited in these measurements mainly by the electronic signal processing and readout methods. Significant progress in these areas is being made as outlined above in this report.

Another investigation into the behavior of such chambers at rates of 10^6 to 10^8 counts/sec is being conducted to obtain information on the effects of the space charge due to positive ion accumulation in the chamber. Smaller avalanche sizes (i.e., lower gas gain) would obviously reduce the space charge. However, with conventional

position-readout methods, this would reduce the signal-to-noise ratio and thus increase the spectral line width. The new centroid finding method provides a solution to this problem.

At very high rates ($\sim 10^9$ sec^{-1}), the use of position-sensitive ion chambers operated in an integrating mode and with many position-sensing electrodes is being considered.

Two-Dimensional Neutron Detectors

These detectors are of the multiwire proportional type, employing ^3He at 4-6 atmospheres as neutron converter and additional gases for reduction of the range of the interaction products, which limits the spatial resolution. Two 20 × 20 cm^2 chambers with 3 mm FWHM resolution have been in successful use at the HFBR for protein crystal structure studies.

A new 20 × 20 cm^2 detector, which should represent a substantial improvement in accuracy, is nearing completion. It has readout grids near ground potential on each side of the anode plane, and cathodes at negative potential. Multitap connections from the readout grids connect to the novel position readout system described above in this report. This system, because of its higher sensitivity, may permit introduction of new gas mixtures for improved spatial resolution and for pulse shape discrimination against the γ-ray background. This detector is intended for small angle scattering facility at the HFBR for use in solid state physics. A larger (50 × 50 cm^2) detector (Fig. 3), based on these concepts, is being developed for use in biological research at the HFBR.

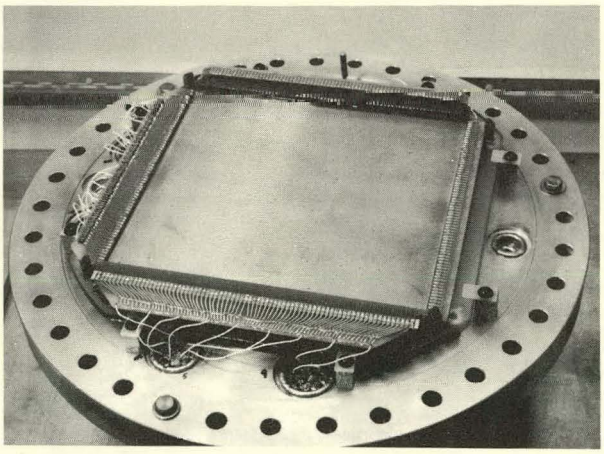

Figure 3. Large area two-dimensional position-sensitive detector for thermal neutrons.

Our new centroid finding method by convolution is being applied to the readout systems for the two large area thermal neutron detectors described above. A system for a 20 × 20 cm^2 detector has been built and extensively tested with a detector simulator. The simulator is arranged to approximate closely the real detector and also to allow parameter variations so that we might test the relationships of signal charge, noise, detector geometry, etc., predicted theoretically for the centroid finding method. The measurements confirm the calculations and indicate a readout limited resolution of 350 μm (FWHM) for a signal charge of 10^{-13} coulomb, and an absolute position error (integral nonlinearity) of less than ± 80 μm.

DATA ACQUISITION AND CONTROL

National Synchrotron Light Source Motor Control Unit

Many experiments to be performed at the National Synchrotron Light Source will require an x-ray monochromator and spectrometer operating under computer control. The prime movers in these devices are usually stepping motors because of the ease with which position may be controlled with this type of motor.

The National Synchrotron Light Source Motor Control Unit is designed to facilitate the operation of spectrometers and monochromators by implementing a simple English-language protocol for all commands to these devices. Although the motor control unit was designed as a slave unit to a larger computer, manual control of the experiment is provided by a local control sub-unit which generates commands conforming to the same protocol. The motor control unit can be adapted to virtually any stepping motor and up to fifteen motors with associated position encoders can be accommodated. Video displays that report the logical status and position of each motor-driven motion in several user-selectable coordinate systems are included with the unit.

Experiment Control System for Two-Dimensional Position-Sensitive Detectors

A data acquisition and experiment control system for small angle scattering experiments uti-

lizing biological samples has been in operation at the Brookhaven High Flux Beam Reactor for the last eighteen months. The main components connected to the system are a neutron spectrometer and a large area, two-dimensional detector for thermal neutrons. A new spectrometer system is being installed that will put all detector motions under computer control. The system architecture is designed so that the analog-to-digital converter for the position-sensitive detector and the experiment control processor (a Digital Equipment Corporation PDP-11/34) have common access to a large array of random-access data memory. The control processor also executes programs for the on-line storage tube display. This arrangement allows displays of the diffraction pattern to be generated and freely manipulated via FORTRAN programs, while data collection from the detector is in progress. Such a feature is essential for setup of an experimental run and calibration of the detector electronics.

Monitoring System for the Superconducting Transmission Line Facility

A computer system developed for the Superconducting Transmission Line Facility of the Accelerator Department has been used for monitoring purposes during initial refrigeration checkout of the 100 meter superconducting power transmission test line. The system, consisting of commercially available computer processors and analog signal conditioning and data acquisition equipment, logs resistor and thermocouple temperature sensor readings at specified time intervals, and indicates sensor values which are outside designated operating ranges. A CRT display and digital sensor interrogation capability is currently being developed, as is a program development station which will give users on-site program editing, compilation, and linking capabilities.

Oceanographic Instrumentation

Oceanographic instrumentation development has been proceeding in close collaboration with the Oceanographic Sciences Division of BNL. One result of this development effort is that significant biological and supporting physical oceanography research programs in continental shelf regions will require less dependence on expensive ship-based research cruises in the future. Synoptic measurements over broad geographical shelf areas can be achieved only with moored buoy and satellite telemetry systems. The Instrumentation Division program is based on development of low-power moored buoy instrumentation for biological and physical measurements and the applications of interrogated satellite telemetry for retrieval of data.

A typical moored buoy will contain a variety of biological and physical sensor clusters at different depths. A low-power system of distributed data acquisition clusters is being developed, connected via serial line communication to a satellite telemetry control processor near the surface. Each local cluster data acquisition system contains an RCA 1802 CMOS microprocessor controller with specific read-only memory based programs for the particular sensors. The cluster processor system will control measurements from sensors, perform any basic calculations, and format and store data for later transmission to the satellite in response to interrogation. Since the GOES (Geostationary Operational Environmental Satellite) transponder permits data bit rates of 100 Hz, the data are verified, condensed, and formatted, without sacrificing required accuracy.

SEMICONDUCTOR DETECTORS

Between 1974 and 1977, the Instrumentation Division designed and tested the prototype x-ray detector system (Fig. 4) and signal processing electronics used in the Einstein x-ray satellite previously called HEAO-B and after launch in November, 1978, HEAO-2. The energy dispersive x-ray spectrometry system completed a very successful year of observations ending as planned in November, 1979, with the loss of the required solid cryogen cooling for the semiconductor detector spectrometers.

The x-ray spectrometer system was capable of resolving individual characteristic elemental x-rays down to oxygen in atomic number, with 125 eV system energy resolution. Two separate units were used in the satellite, one being a complete back-up system. The lithium-drifted silicon [Si (Li)] energy dispersive x-ray detector, supplied by Ortec, Inc., was fabricated with an extra-thin gold entrance layer and operated in an essentially "windowless" configuration in order to extend its sensitivity to elements as light as oxygen,

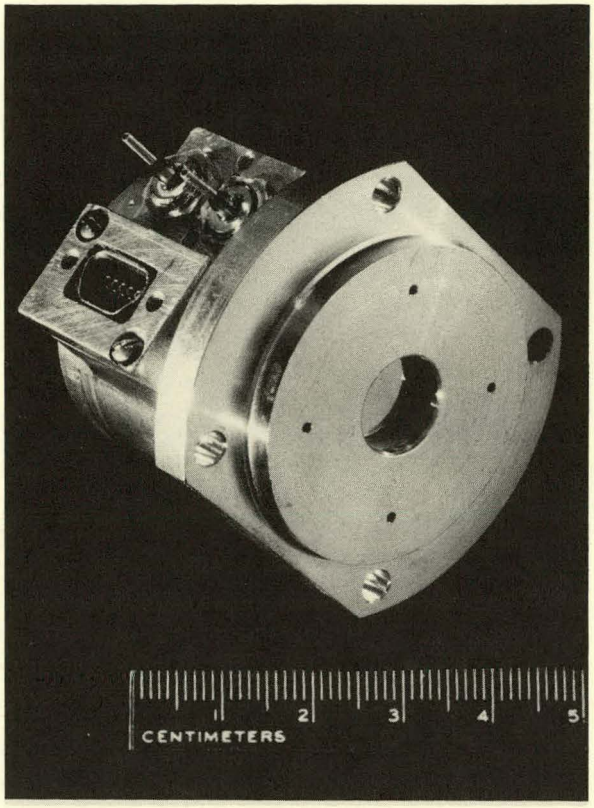

Figure 4. Prototype semiconductor detector package developed for the Einstein Satellite (HEAO-2) which includes a Si(Li) x-ray spectrometer and high purity germanium rejection detector as well as some signal processing electronics.

which emits very low energy characteristic x-rays. In the same detector container, approximately 16 cm^3 in size, a high-purity germanium detector, produced by BNL, was mounted behind the Si(Li) detector to reject events in the Si(Li) that might be common due to either scattering or charged particle penetration.

Prototypes of the amplifiers with optoelectronic feedback, analog filtering networks, and gating circuitry were developed and built at BNL. They were used for laboratory testing and later copied and packaged by NASA for flight use.

Discoveries made with this spectrometer system include the observation of x-rays characteristic of highly excited Mg, Si, S, and A atoms in remnants of supernovae and several properties of rapidly rotating magnetic stars using information both from the x-ray continuum and discrete lines.

ELECTRON MICROSCOPY AND ANALYTIC TECHNIQUES

The Instrumentation Division Microscopy Laboratory continues to expand and now has three electron microscopes, configured for different areas of investigation. Two active research topics utilize the AMR scanning electron microscope (SEM) with a Tracor Northern energy dispersive x-ray attachment, and a Philips transmission electron microscope (TEM) equipped with a goniometer stage.

The imaging capabilities of the SEM are of particular use to examine biological ultrastructure by a technique called soft x-ray contact microscopy (Fig. 5). With this method, biological samples are prepared by placing them on a layer of photoresist and exposing them to x-rays 1 to 10 nanometers in wavelength. Differential x-ray absorption by local density variations in the sample causes the photoresist to be exposed to different degrees in different areas. When the photoresist is chemically developed, this differential exposure results in replication of the specimen fine structure. This photoresist replica can then be examined in the SEM, and image topography can be related to elemental distributions in the sample.

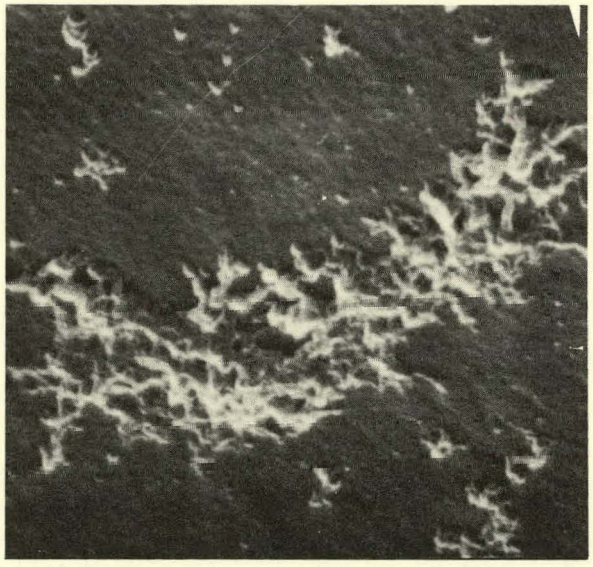

Figure 5. SEM image of soft x-ray contact replica of cytochrome C-treated-molecular aggregates (proteoglycans), derived from cartilage, reveals extensive ultrastructural detail. The highest points on the replica may represent sites of iron localization.

The Philips TEM is now being modified with a special objective lens that can focus an electron beam to a diameter of 5 nm. A probe of this size is necessary for both energy dispersive x-ray analysis and for microdiffraction, a method of obtaining electron diffraction patterns from very small regions of a crystalline sample. These microdiffraction patterns (Fig. 6) can be used to determine the precise orientation of a crystal with respect to the electron beam and are useful in investigating localized misorientations associated with crystal defects such as dislocations. Current work will use this method to characterize polycrystalline silicon.

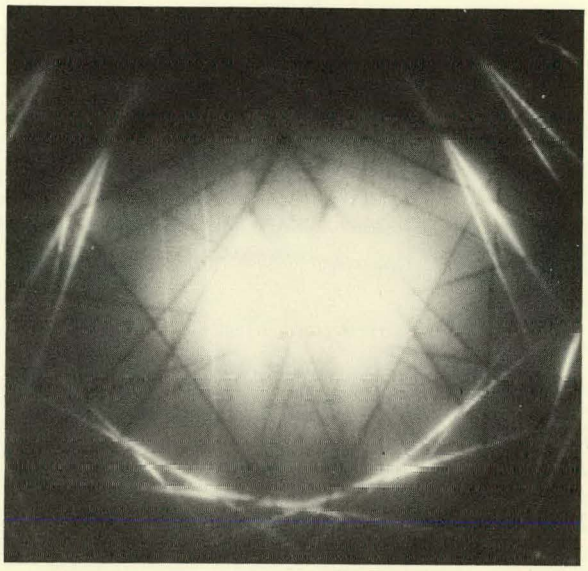

Figure 6. Microdiffraction pattern from 10 nm diameter area in silicon. Analysis of the sharp lines (Kikuchi lines) enables the exact electron beam/crystal orientation to be calculated.

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INSTRUMENTATION DIVISION
V. Radeka, Division Head

J.L. Alberi ..... Detectors, Systems
R.A. Boie ..... Electronics
R.P. DiNardo ..... Vacuum Technology
D.G. Dimmler ... Systems, Oceanographic Instrum.
J. Fischer ..... Detectors
E. Gatti* (visiting) ..... Detectors, Electronics
N.E. Greenlaw ..... Systems
M.E. Hofmann ..... Systems, Electronics
A.T. Hrisoho† (visiting) ..... Electronics
Y. Inagaki‡ (visiting) ..... Detectors
M.A. Kelley ..... Systems
H.W. Kraner ..... Nuclear Analytic Techniques
G.P. Larson ..... Systems
W.R. McKinney ..... Optics
H. Okuno§ (visiting) ..... Detectors
D.W. Potter ..... Electronics
V. Radeka ..... Electronics, Detectors
S. Rankowitz ..... Systems, Electronics
L.C. Rogers ..... Electronics
F.W. Stubblefield ..... Systems, Medical Electronics
P.Z. Takacs ..... Optics
A.H. Walenta ..... Detectors
J.B. Warren ..... Electron Microscopy

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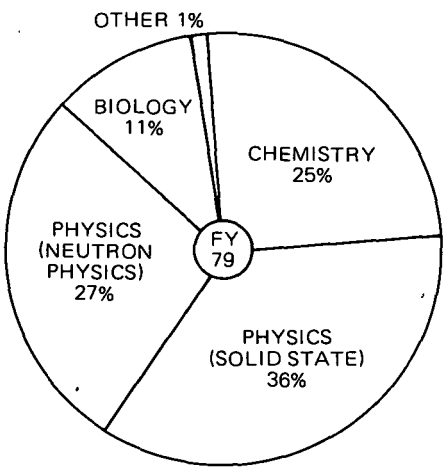
Reactor Division

The Reactor Division is charged with the responsibility of operating BNL's two nuclear reactors in a safe and economical manner while providing neutrons used in beam experiments and for the irradiation of specimens. The High Flux Beam Reactor (HFBR) produced over 11,000 megawatt days of integrated thermal energy during the past year, with only 7 unscheduled interruptions. Five of these seven interruptions were caused by loss of commercial electrical power. Unscheduled reactor downtime amounted to 3.3% overall. The Brookhaven Medical Research Reactor (BMRR) was run only upon demand, and produced 268 megawatt hours of energy during the past year.

Table I shows the distribution of the support of HFBR Operations from the scientific programs, and Table II lists the service irradiations performed.

Table I

Distribution of Support of HFBR Operations from Scientific Programs



	Use Charges	
	Fiscal Year 1979	
	Amount $	% of Support
Physics Department		
Neutron Physics	650,004	27
Solid State Physics	843,996	36
Biology Department		
Analysis of Biological Structures	258,996	11
Chemistry Department		
Molecular Chemistry	585,000	25
Other		
Energy and Environment Department Irradiation Services	12,996	1
Total	2,350,992	100

Table II

Reactor Service Irradiations FY 79

BROOKHAVEN	HFBR	BMRR
Chemistry Department	243	3
Department of Energy and Environment	28	1
Department of Nuclear Energy	19	1
Medical Department	4	3
Physics Department	2	9
Reactor Division	2	14
Safety and Environmental Protection Division	1	15
OUTSIDE ORGANIZATIONS	30	53

IMPROVEMENTS TO THE HFBR AND RELATED EXPERIMENTAL FACILITIES

60 MW Conversion

During the past year the project to increase reactor power from 40 MW to 60 MW neared completion. New heat exchangers were fabricated and tested, modifications to the cooling towers were begun, and the necessary modifications to the shutdown heat removal system were completed. In addition, the major part of the revised safety analysis has been completed. It is expected that the reactor will be ready for 60 MW operation with a corresponding 50% increase in avail-

able neutron flux early in 1980, after installation of the heat exchangers has been accomplished and all safety reviews have been completed.

Construction of New Experimental Facilities

Several new experimental facilities which have been under development drew near to completion during the past year. Nearly all are expected to be ready for use early in 1980.

A Cold Neutron Facility was installed in beam port H-9 while acceptance tests were carried out; however, the development of a leak in the vacuum chamber of this facility required its removal for repairs. Modifications to an auxiliary cooling system and improvements to the instrumentation have been made, and it is anticipated that the facility will be reassembled and ready for operation again early in 1980.

A high precision double-focusing electron spectrometer has been installed at H-3B and is in the final stages of being fine-tuned. When operational, this instrument will be used in the study of internal conversion electrons emitted when slow neutrons are captured by nuclei.

TRISTAN II, an on-line isotope separator for the spectroscopic study of neutron-rich unstable isotopes produced from U-235 fission, has been added to the H-2 beam line. This device can be operated interchangeably with the fast chopper which previously was installed at H-2, and will be used to study the decay of nuclei far from the line of stability.

New spectrometers have been constructed for beam ports H-5 and H-8 which will permit automatic operation by means of computer control over a wide range of angles. In addition, the shielding in these spectrometers has been improved to reduce the background radiation at these facilities. These instruments will be installed during the reactor shutdown for installation of the 60MW heat exchangers, and will increase greatly the usefulness of these beam ports for experiments in chemistry and solid state physics.

Construction has also begun on a new spectrometer for biology experiments at beam port H-3A. This spectrometer will feature a very compact shield arrangement which permits the experiments to be moved closer to the reactor, increasing the intensity of neutrons available in the beam. It is anticipated that this instrument will be ready for use early in 1981.

REACTOR DIVISION

R. W. Powell, Division Head

R. Bergoffen	P. Colsmann	S. Moss	G. D. Pitcher
M. Brooks	K. Dahms	D. Oldham	D. Rorer
W. Brynda	J. Detweiler	J. Penny	P. Tichler
K. Y. Cheung	R. Karol	J. Phillips	W. Wilson

Safety and Environmental Protection Division

INTRODUCTION

The Safety and Environmental Protection Division provides technical and professional services in areas of health and safety. It also carries on basic and applied research in these areas. Its health and safety services include: professional consultation, guidance, and review of safety aspects of new facilities or programs; sampling, analysis, and evaluation of potentially hazardous operations already in existence; development of safety guides; waste management; also training in industrial safety, cardio-pulmonary resuscitation, respirator use, health physics, industrial hygiene, fork truck and crane safety, and emergency response. The Division's fire-fighting and police groups play key roles in ensuring that the Laboratory can cope effectively with local emergencies.

The Division is responsible for nine research programs which relate to the evaluation of potential health and safety hazards of energy sources or byproducts. These programs include: two directed at evaluation of the past and anticipated future ionizing radiation dose equivalents to residents of the Marshall Islands; two which involved studies of basic quantities in radiological physics and their relationship to biological effects of ionizing radiation and other agents having carcinogenic or mutagenic potential; two in the area of assessment of hazards and development of protection guidelines for chemical and physical hazards; two in which genetic effects of energy-related agents, e.g., strong magnetic fields and gasoline additives, are studied; and one which provides practical field training and research experience for graduate students in radiological and environmental sciences.

THREE MILE ISLAND REACTOR INCIDENT

Under the Department of Energy's Radiological Assistance Plan (RAP) fifteen BNL health physicists were involved on the scene at the Three Mile Island nuclear power station between March 28 and April 17, 1979 in connection with the reactor incident at Unit 2.

The first notification to the BNL RAP team was made by the plant operator at 0710. Based on the request of the Bureau of Radiological Health, of Pennsylvania's Department of Environmental Resources, the first six-person team was dispatched by helicopter about noontime on the 28th. Shortly after their arrival, they measured radiation levels of a few mR/h at distances of 8-16 km from the plant and established that airborne concentrations of ^{131}I were below a minimum level of detection of 6×10^{-11} $\mu Ci/cm^3$ (the MPC for continuous off-site exposure is 1×10^{-10} $\mu Ci/cm^3$). Similar levels were found the next morning. The ability of a BNL-developed portable field sampler to collect radioiodines and to discriminate against radiogases was demonstrated during this and on subsequent occasions at TMI.

The BNL team, which had been joined by five additional persons who had arrived by truck with backup supplies and equipment, was replaced by one from the Bettis Atomic Power Laboratory on the afternoon of March 29th. The team was subsequently recalled on March 30th, when concerns were raised about the potential of a meltdown, due to the presence of a hydrogen bubble in the reactor vessel and the fact that it might combine explosively with radiolytic oxygen. (This fear was subsequently shown to be groundless.)

During the next two weeks, the BNL team functioned as part of a comprehensive effort by DOE which utilized members of several of its major laboratories. In addition to making field measurements and performing field sampling, the BNL team was responsible for setting up and operating a component of a temporary counting laboratory for the gamma analysis of samples of air, water, vegetation, and soil with equipment that had been requisitioned from BNL and other regional DOE facilities. A senior member of the BNL team also had a principal responsibility for calculation of the population dose equivalent, on the basis of all the available environ-

Table I
Summary of Long Term Biological Removal Rate Constants for Cs-137

Population	Age years	Group	Sample size	Rate constant 1/days	Standard deviation
Adult Males	23-55	ICRP	_	0.006	—
	23-55	NCRP	4	0.0051	—
	23-55	NCRP	26	0.0066	0.0016
	22-59	BNL	10	0.0061	0.0015
Adult Females	20-51	NCRP	15	0.0082	0.0020
	19-70	BNL	21	0.0084	0.0015
Adolescents	11-15	BNL	7	0.011	0.0021
Juveniles	5-17	NCRP	7	0.012	0.0043
	5-10	BNL	9	0.018	0.0036

mental radiation data obtained by the DOERAP teams and by other agencies.

RADIOLOGICAL RESEARCH ACCELERATOR FACILITY[1-3]

During the past year, the Radiological Research Accelerator Facility has operated as a national facility for radiobiology using high LET radiations. Irradiations and beam time have been provided for five experiments conducted by outside users, six by users from the Radiological Research Laboratory of Columbia University, and five by BNL users. The systems studied include mutation in *Drosophila melanogaster,* late effects in rat fetuses irradiated *in utero,* and effects on cells grown in tissue culture. Unique studies, using spatially correlated ions to irradiate Chinese hamster V79 cells synchronized in late S phase, were extended to larger ion separations. Correlated protons were used and enhanced cell killing was obtained with mean ion separations as large as 0.4 μm.

MARSHALL ISLANDS STUDIES[4-5]

Three personnel monitoring field trips to assess the body burden of radioactivity of former Bikini residents, as well as those of current residents of Rongelap and Utirik, were undertaken by the Marshall Islands Radiological Safety Group. The information obtained, along with internal and external dose assessments for Bikinians, has been incorporated in recent reports. Currently, adult and child body burdens are within the International Committee on Radiation Protection's recommended limits for the general public. The whole body counting unit used for these assessments was changed from a single shadow shield design to dual chairs in order to accommodate the increasing number of people to be counted. Uptake, retention, and excretion studies involving ^{137}Cs indicate the physiological loss rate constant is inversely related to body mass. Thus, smaller adults and children eliminate this nuclide more rapidly than the adult male (Table I).

The incidence of benign and malignant thyroid nodules in the populations of Utirik and Rongelap which were exposed to fallout on March 1, 1954 was comparable, although the reported external radiation levels at Utirik were about ten times less than at Rongelap. Previous internal dose estimates appear to have been based on incomplete data analysis. Therefore, studies have been initiated to reexamine all the data from available reports and to consult with scientific personnel involved at the time of the tests. In addition, advanced analytical and computer techniques are being used to estimate the immediate post-test concentrations for the radioiodine isotopes principally responsible for irradiation of the thyroid glands from inhaled and ingested fallout nuclides.

MUTAGENIC EFFECTS OF POLLUTANTS[6-8]

Genetic effects of strong magnetic fields, neutron and gamma radiations, 1,2-dibro-

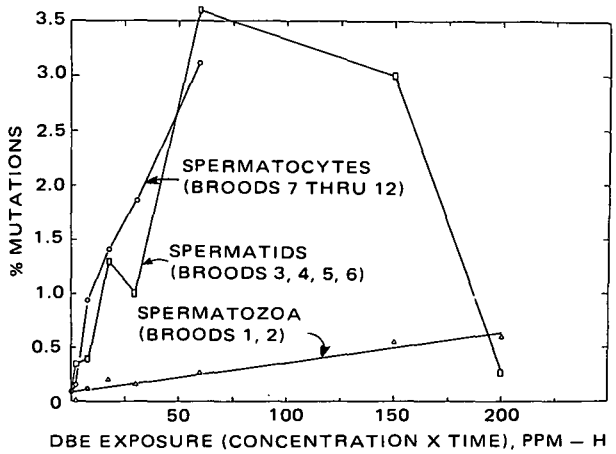


Figure 1. Dose-response for recessive lethal mutations in *D. melanogaster* Canton-S males exposed to gaseous concentrations of 1,2-dibromoethane.

moethane (a gasoline additive), and cigarette smoke were studied by scoring sex-linked recessive lethal mutations in *Drosophila melanogaster* (fruit flies). Strong magnetic fields did not induce detectable mutations and did not influence the number induced by simultaneous exposures to neutron and gamma radiations. Both cigarette smoke and 1,2-dibromoethane were mutagenic. For the latter, differential germ-cell sensitivity was studied and large sensitivity differences were observed. For low exposures, spermatids and spermatocytes were about 10-20 times more sensitive than spermatozoa (Fig. 1). The dose-effect relations were linear below 60 ppm·h for the three cell types. At higher exposures, sterility prevented mutation detection in spermatocytes and in spermatogonia.

TOXIC MATERIAL ADVISORY PROGRAM

The Toxic Material Advisory Program provides the basic foundation to develop interim exposure guidelines, work practices, and consultation in the functional areas of toxicology, physiology, biological monitoring, workplace sampling, health assessment methodologies, risk assessment, hazard analysis, and ergonomics. Initially, the Center for Assessment of Chemical and Physical Hazards has been established within the Safety and Environmental Protection Division to facilitate the timely development of interim standards for potential occupational and environmental hazards that may be associated with activities of the Department of Energy. At the Center, particular emphasis is directed toward the development and eventual promulgation of interim standards for those energy technologies having high probability of commercialization. Key factors associated with the establishment of this support program are flexibility and the ability to respond to changing problems with multi-disciplinary expertise.

Although several avenues, OSHA's Standards, NIOSH's Criteria Documents, AIHA's Hygienic Guides, MCA's Chemical and Safety Data Sheet, etc., provide information on toxic and hazardous materials/agents, guidelines for toxic substances particular to the Department of Energy's needs may not be recognized soon enough to facilitate timely and authoritative guidance. The Center has been staffed and equipped to respond to the flexible and demanding needs often associated with the emerging energy technologies. The staff, equipped with state-of-the-art tools for reference retrieval and document editing, anticipates producing ten summary documents and five Toxic Material Advisory Reports within each fiscal year.

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SAFETY AND ENVIRONMENTAL PROTECTION DIVISION

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W.R. Casey, Deputy Division Head
J.W. Baum, Research Coordinator
R.W. Young, Security Officer

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J.W. Baum	Radiological Physics, Health Risk Assessments
P.R. Becker	Safety Engineering, Marine Safety
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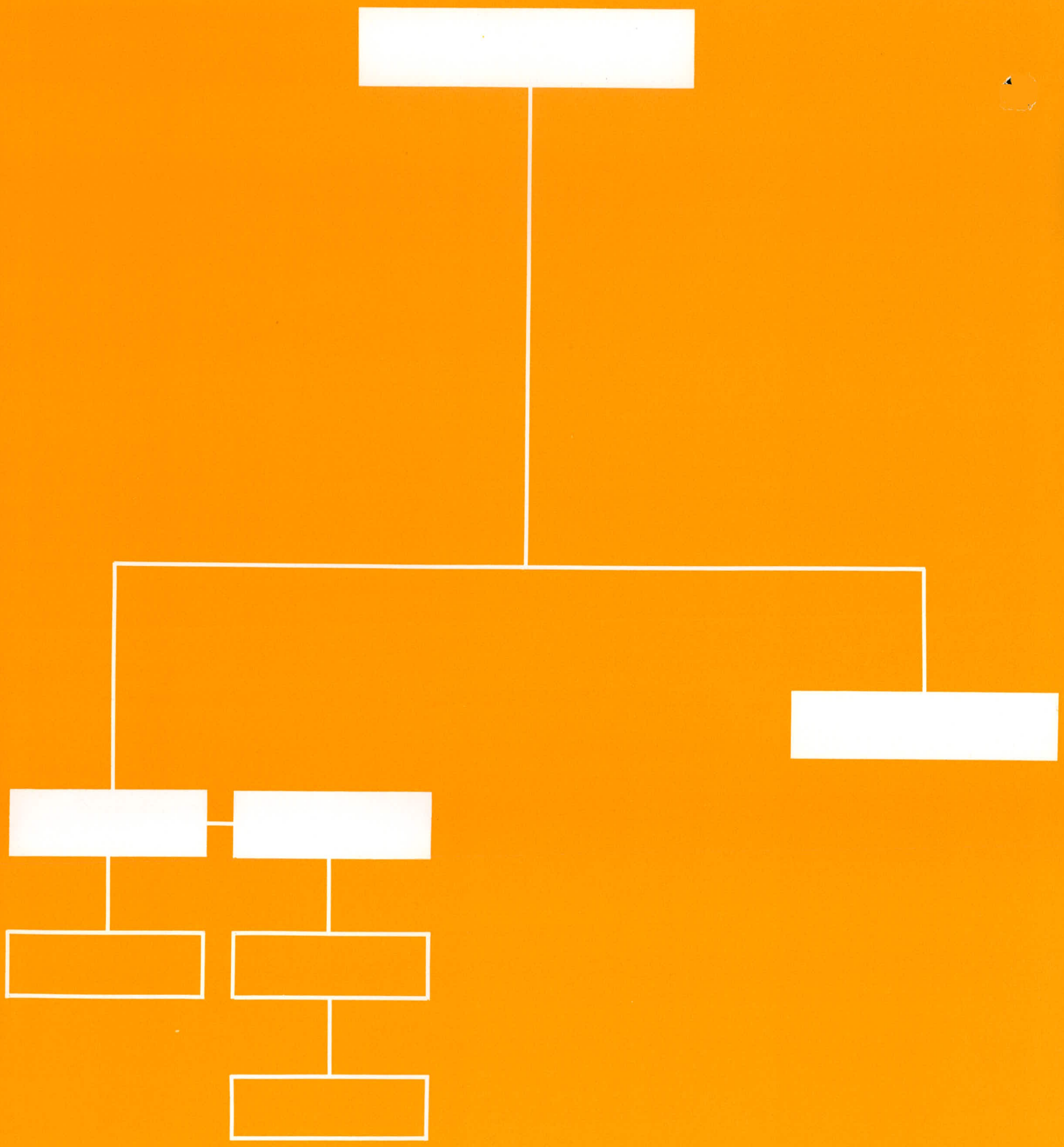
O. White	Industrial Hygiene
R. Young	Safety Engineering, Security

General and Administrative



General and Administrative

PERSONNEL STATISTICS

Total employment, as shown in Table I, has slowed down in the past three years and is tending to level off. Growth in 1977 was 14.2%, in 1978 7.2%, and in 1979 a mere 3.1%. This trend probably reflects the slowing down in staffing of the two new major research facilities, ISABELLE and the National Synchrotron Light Source.

Table II shows growth is also slowing down in the scientific staff and in student participation. Growth in 1977 was 10.4%, plus 7.7% in 1978, plus 0.8% in 1979.

Participants in summer programs (Table III) have shown a steady decline. 1977 registered a 7.1% increase, 1978 a .02% increase, and 1979 an 18% decrease.

In Table IV, scientific guest and collaborator appointments increased in 1979 by 5.6% over 1978.

Likewise, over the last three years the number of mandays of consultant service (Table V) has increased. 1977 was up 50% over 1976, 1978 up 27% over 1977, and 1979 up 42% over 1978.

Table I
Employment Statistics

	Sept. 30, 1979	Sept. 30, 1978	June 30, 1977
Scientific staff [a]	765	763	717
Scientific professional staff	560	526	413
Nonscientific staff [b]	2242	2170	2094
Total	3567	3459	3224

Turnover Data

	1979		1978		1977	
	Number	Annual rate (%)	Number	Annual rate (%)	Number	Annual rate (%)
Accessions						
Scientific staff [a]	126	17	173	23	148	21
Scientific professional staff	107	19	135	26	80	20
Nonscientific staff [b]	238	11	310	14	215	11
Total	471	13	618	18	443	14
Separations						
Scientific staff [a]	102	13	135	18	94	13
Scientific professional staff	82	15	78	15	33	8
Nonscientific staff [b]	178	8	199	9	146	7
Total	362	10	412	12	273	9
Net Accessions						
Scientific staff	24	3	38	5	54	8
Scientific professional staff	25	5	57	11	47	12
Nonscientific staff	60	3	111	5	69	4
Total	109	3	206	6	170	5

[a]Includes Research Associates and Visitors.

[b]Figures do not include temporary summer nonstudent employees. Temporary student employees are included in Table III.

Table II

Scientific Staff and Students on May 31

	Regular Staff			Salaried Visitors		
	1979	1978	1977	1979	1978	1977
By appointment category						
Staff						
Senior Scientist	107	123	114	1	2	1
Scientist	272	255	220	11	11	8
Associate Scientist	169	162	150	8	8	7
Assistant Scientist	81	84	95	1	3	3
Senior Research Associate	–	–	–	11	12	8
Research Associate	–	–	–	69	72	70
Students						
Junior Research Associate	–	–	–	12	10	12
Research Assistant	–	–	–	3	–	–
Total	629	624	579	116	118	109
By academic degree						
Ph.D. or M.D.	523	513	472	97	114	92
Master	42	46	45	11	3	10
Bachelor	59	61	62	8	1	7
No degree	5	4	4	–	–	–

Table III

Summer Program 1979

	Staff	Students[a]	Salaried	Unsalaried	Institutions
By department					
Accelerator	8	11	5	14	12
Applied Math	5	1	3	3	6
Biology	11	9	6	14	18
Chemistry	10	6	3	13	16
Directors' Office	–	2	–	2	2
Energy & Environment	19	31	11	39	35
Instrumentation	1	2	1	2	3
Medical	3	14	–	17	14
Nuclear Energy	8	9	7	10	17
Physics	92	15	32	75	71
Safety & Environmental Protection Division	1	26	–	27	15
Total	158	126	68	216	

[a]Includes 69 participants in Summer Student Program for 1979.

AFFIRMATIVE ACTION

The numbers of ethnic minorities and of women at the Laboratory have grown 5.8% and 3.4% respectively in the past year. A representative breakdown for the period spanning October 1978 to September 1979, of Black, Hispanic, American Indian or Alaskan Native, Asian or Pacific Islander, and women is presented in Table VI.

Table IV

Scientific Guest and Collaborator Appointments (Unsalaried) in Effect on Sept. 30, 1979

By department	
Accelerator	32
Applied Mathematics	3
Biology	72
Chemistry	161
Energy & Environment	80
Instrumentation	8
Medical	256
Nuclear Energy	7
Physics	769
Reactor	36
Safety & Environmental Protection Division	41
Total	1465[a]

[a]Represents 292 institutions, including 74 outside North America.

Table V

Consultant Services

	1979 Fiscal year
Total contracts in effect	303
No. of consultants used	213
No. of man-days of service	5,996.79

Table VI

Minority Employees

	10/1/78		9/30/79	
Category Totals	No.	%	No.	%
Minority	465	13.5	492	13.8
Black	248	7.1	248	7.0
Hispanic	72	2.1	79	2.2
American Indian/ Alaskan Native	10	0.3	12	0.3
Asian/Pacific Islanders	140	4.1	153	4.3
Women	735	21.4	760	21.3

Currently 58% of all minorities and 51% of all women hold positions in the top three Federal Equal Employment Opportunity Job Categories. A woman was selected to become Head of the Laboratory's Technical Information Division.

The Laboratory was accepted for membership by the National Consortium for Graduate Degrees for Minorities in Engineering (GEM). The Consortium is a non-profit organization which is national in scope that was established to encourage minority students to obtain practical engineering experience through summer work opportunities, and in financing graduate students towards a master's degree in any of the various disciplines in engineering. The Laboratory will host four GEM interns starting in June 1980.

The Laboratory has conducted a Craft Apprentice Program since 1969 which has been very effective in increasing the pool of qualified craftsworkers in the following job groups: Refrigeration & Air Conditioning, Electrician, and Experimental Machinist. The year 1979 provided the occasion for three first events since the Craft Apprentice Program has been in existence. A black male and a white female were certified as electricians in this calendar year and a black male as an Experimental Machinist.

ADMINISTRATION

On October 10, 1978, Mr. Jagdish R. Dalal was appointed Manager of the newly formed Management Information Systems.

On February 1, 1979 Dr. Warren E. Winsche was appointed Deputy Director.

On July 1, 1979, three new appointments were announced: Dr. Donald C. Borg became Chairman of the Medical Department, succeeding Dr. Eugene P. Cronkite; Dr. Ronald Peierls became Chairman of the Applied Mathematics Department, succeeding the Acting Chairman, Arnold Peskin; and Mr. Bernard Manowitz became Chairman of the Department of Energy and Environment, succeeding Dr. Kenneth C. Hoffman.

SERVICE ORGANIZATIONS

Division of Contracts and Procurement

During the fiscal year the Division of Contracts & Procurement negotiated over $950,000 in savings for the Laboratory.

Concern with the increasing level of R&D subcontracts has led to the development of a Statement of Cost form which all subcontractors must complete to help in determining legitimacy of costs.

During FY 1979 the division handled 38,000 transactions totalling more than $50,000,000; a significant increase in both transactions and dol-

lars. Included in these figures was $18,000,000 spent with 1500 local firms, an increase of 50% over the prior fiscal year.

Fiscal Division

The installation of an inquiry terminal in General Accounting for the accessing of data regarding the inventory system has been most helpful. Expansion of the inquiry system is expected to apply to other systems in the future.

An all-time high was reached in Accounts Payable with the processing of 55,000 vouchers as compared to the former high of 48,000 in 1968. This was accomplished in spite of a one-third reduction in staff.

Photography and Graphic Arts Division

The Daconics Word Processing/Text Editing System was expanded by the addition of two terminals. Two terminals and two printers operate as satellites. Production on the five terminals and two printers of the centralized system increased by 14% from 39,442 pages in FY 78 to 44,857 pages in FY 79.

The Comp-80 was improved during the year by the addition of a high-throughput feature which doubled recording speeds. COM (Computer Output Microfilm) frames increased by 28% from 6,468,873 frames in FY 78 to 8,248,073 frames in FY 79.

Three state-of-the-art film processors were purchased for installation in the Photography Group, to replace obsolete processing systems.

Plant Engineering

Improved scheduling of construction projects was possible because of increased use of outside architect-engineering firms for Titles I, II, and III. Five projects totalling over $900,000 were initiated on this basis.

Continued use of alternate liquid fuels enabled BNL to save $690,000.

A study funded by the Town of Brookhaven and BNL determined the feasibility, both economically and environmentally, of a Municipal Solid Waste to Energy Generation Facility.

Maintenance management objectives are being met through the introduction and establishment of systematic estimating procedures, scheduling, material control, development of a computerized preventive maintenance program, machinery history, and use of computerized programs for control function.

Accurate scheduling of craft assignments on a weekly basis is a direct result of the material control system and use of Engineered Performance Standard (EPS) estimated times.

Staff Services Division

In April, Brookhaven National Laboratory received approval and funds from the Department of Energy to participate in the Federal Agency Electric and Hybrid Vehicle Demonstration Project. Thirteen electric vehicles are on order with delivery expected in the first quarter of FY 80.

Fiscal year 79 saw the completion of a two-year effort in our records management program at BNL. All administrative records, scientific records, and machine readable data have been scheduled on Records Inventory and Disposition (RID) schedules in accordance with the DOE Records Disposition Manual. A complete set of RIDs for BNL have been forwarded to the Chicago Operations Regional Office.

Supply and Materiel

The Property Management, Excess Procurement, and Traffic Sections assisted the Accelerator Department in the deactivation and transfer of equipment from the Space Radiation Effects Laboratory to Brookhaven National Laboratory. This transfer included the complete inventory, cataloging, and tagging of capital equipment, the disposition of non-useable scrap and expendable materials, and the movement of shielding blocks in excess of 9,000 tons(m).

Emphasis was placed on establishing more blanket orders for the acquisition of stores materials which resulted in a cost savings of $44,000 for the Laboratory.

Technical Information Division

A complete scientific bibliographic retrieval service is now provided to the scientific staff by using all major scientific abstracting and indexing journals as well as the numerous computerized data files searched on line from the services offered by Lockheed Dialog, SDC, Orbit, SLAC's high energy reprint file, and the DOE RECON energy data base. This broad subject range of files was added to by acquiring the ability to search the major national medical data base, MEDLINE. As this service has been expanded, the demand for it has increased annually by 25%.

A service of selective dissemination of bibliographic data of interest to individual scientists has begun with the cooperation of the Argonne National Laboratory Technical Library. Several Brookhaven profiles have been compiled and have been incorporated with the Argonne profiles. Weekly print outs are now received regularly from ANL. The Research Library's interlibrary loan program appears to have stabilized after a steady increase in borrowing by the Research Library for the past three years. The expanded interests of the Laboratory in recent years have forced the library to borrow heavily from other sources until a collection of materials has been acquired to meet these new demands. For the first time in several years, a slight drop in items borrowed by BNL has occurred. Requests from other libraries for BNL books and journals increased by 25%. Project BLISS, the computerized journal subscription record system, established with the assistance of ADP, is now fully operational.

A significant response has been noted as a result of the efforts made to increase the number of BNL reports that are edited. The publication manual, two seminars on technical writing, and consultations with Department Chairmen have stimulated the editorial assignments which have more than doubled over the past year.

ENERGY CONSERVATION

During fiscal year 1979, a separate energy management coordination group was established in Plant Engineering, reporting directly to the Manger of Plant Engineering. The primary thrust of this group is to develop energy conservation opportunities (ECOs) for implementation that will reduce the Laboratory's consumption of electric power and fossil fuels without impairing the scientific program. The long range Laboratory goal is to reduce energy consumption in buildings and facilities by 20% in fiscal year 1985 compared with energy usage in fiscal year 1975.

An energy usage audit of the complete site, building, and facilities was completed by Pope, Evans and Robbins early in fiscal year 1979. The energy consultant recommended 489 ECOs at an implementation cost of 6.6 million dollars. Fifty-three of the ECOs are either in design, construction, or implemented at a cost of $300,000. Funds have been requested for 74 more ECOs at an implementation cost of 4.4 million dollars.

The Department of Energy has provided BNL through its in-house energy management retrofit program with 1.5 million dollars in fiscal years 77, 78, and 79. When all of these projects are implemented, the ECOs are expected to save approximately 160 billion BTUs annually. This 160 billion BTUs reduction represents 9% of the total energy used in building and facilities (excluding experimental power) in fiscal year 1979.

Examples of energy conservation retrofit projects completed in fiscal year 1979 are:

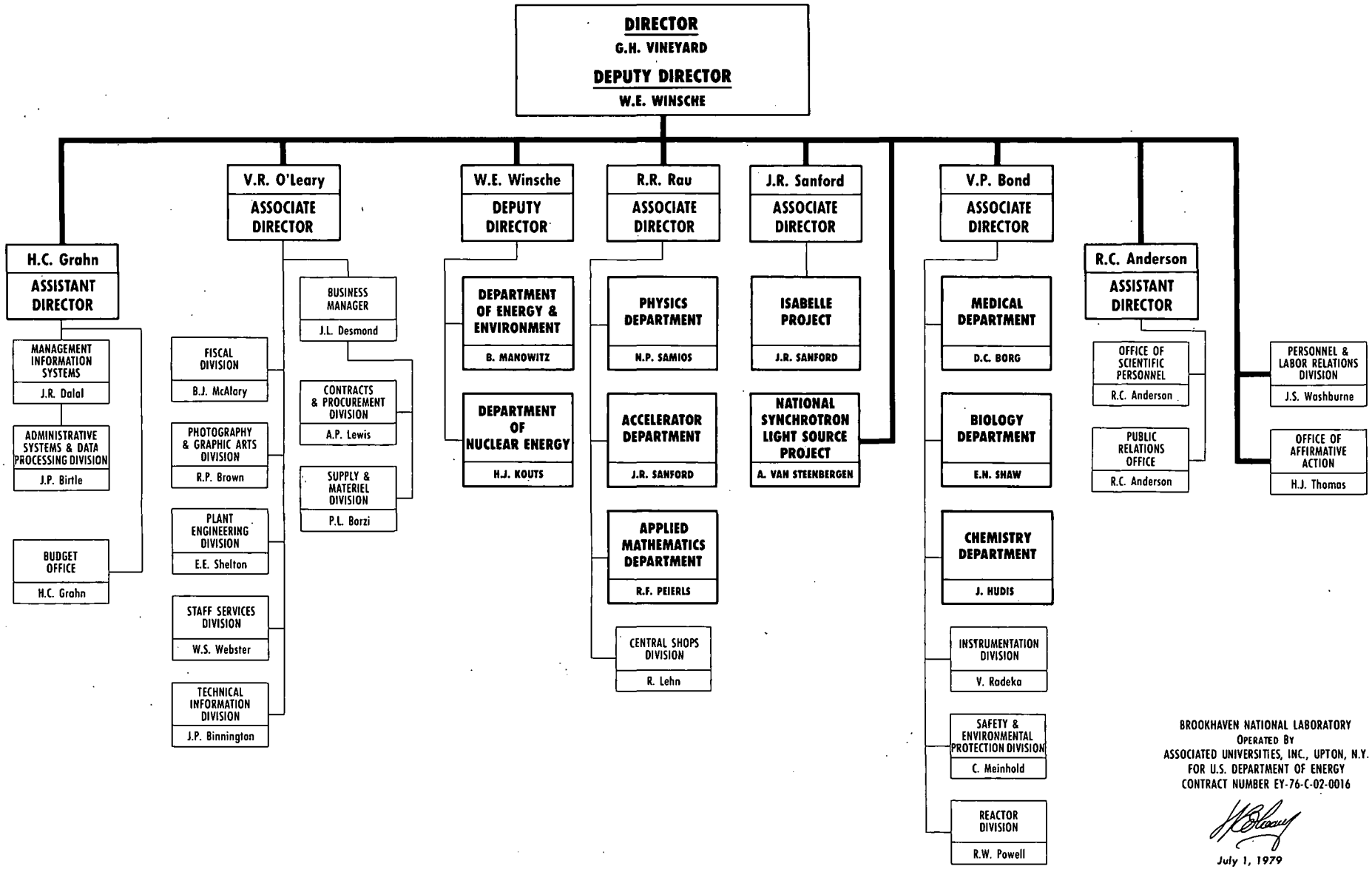
a) Night setback and equipment turn-off in various buildings.
b) Equipment modifications to major refrigeration systems (e.g., steam absorption and centrifugal water chillers) to reduce energy input per ton output.
c) Installing or increasing the amount of wall and roof insulation on the wooden buildings throughout the site. Adding exterior foam insulation to trailers, metal and masonry buildings.
d) Relamping selected buildings with high efficiency, low energy usage fluorescent and high pressure sodium fixtures.

Vanpooling

In May 1979, Associated Universities, Inc. purchased three twelve-passenger vans to test the acceptability of the Vanpooling concept to BNL employees. The pilot program proved to be successful, over 800 employees have expressed an interest in joining a Vanpool.

Plans to expand the program through an employee-owned van concept were initially burdened with problems relating to insurance, registration, and licensing requirements in New York State. These difficulties have been resolved, and the recent announcement of the expansion of the program through employee ownership of the vans has stimulated considerable employee interest. Approximately 20 employees are currently giving serious consideration to purchasing a van. It is believed the Brookhaven National Laboratory has provided the leadership in New York State for the expansion of Vanpooling programs through employee ownership.

BROOKHAVEN NATIONAL LABORATORY



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CONTRACT NUMBER EY-76-C-02-0016

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