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BROOKHAVEN HIGHLIGHTS

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BROOKHAVEN HIGHLIGHTS

A TWO YEAR REPORT

HIGH ENERGY PHYSICS

BASIC ENERGY SCIENCE

LIFE SCIENCES

APPLIED ENERGY SCIENCE

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

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Introduction

Brookhaven National Laboratory is operated by Associated Universities, Inc. (AUI) under a prime contract with the Energy Research and Development Administration of the Federal government. The Laboratory occupies a 21.31 km^2 (8.23 mi^2) tract of land in Suffolk County, approximately at the geographic center of Long Island, about 100 kilometers east of New York City.

The formation of AUI in 1946 and the establishment of Brookhaven National Laboratory at Upton, New York, provided a new approach to the support of fundamental research by the Federal government, especially for large-scale scientific enterprises of interest to the academic community.

The primary objectives of the Laboratory are:

–To seek new knowledge in the nuclear sciences and related fields, with emphasis on programs that require such large-scale research tools as nuclear reactors, particle accelerators, and special laboratories, which are beyond the scope of most or all individual educational institutions.

–To encourage use of its facilities by scientists of university, industrial, and other laboratories.

–To assist the Energy Research and Development Administration (ERDA) in the solution of specific problems that utilize the Laboratory's unique facilities 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.

The principal scientific facilities and the main research themes at Brookhaven are closely linked.

Several main themes may be discerned in the scientific programs at Brookhaven, and often a research project reflects more than one theme. This interplay of themes, the special power of multidisciplinary work, is one of the most important characteristics of Brookhaven.

The first theme deals with the fundamental constituents of matter, their properties, and their interactions. Research, which utilizes all the major machines at the Laboratory, is done on atoms, nuclei, nucleons, and other particles. The most basic questions concern the particles (mesons, neutrinos, hyperons, and other short lived particles) that are created when nucleons collide at high energy.

The second theme encompasses studies of the physical, chemical, and biological effects of radiation and of chemical substances, particularly those arising in the production of energy. The effects of radiation are utilized to determine the characteristics of physical and chemical structures and to elucidate the more complex properties of living systems and the changes they undergo in their life and reproductive cycles.

The third theme centers on the use of nuclear and other special tools, such as neutrons, charged particles, gamma rays, isotopic tracers, and special instruments, in many branches of scientific research. Wide use is made of isotopic tracers in many fields to yield information on the mechanisms and rates of chemical reactions and biological processes. The neutron activation method of analysis, which is nondestructive but offers very high sensitivity for some elements, belongs in this general field.

The fourth theme involves research and development directed toward solving specific problems of national interest in the field of energy development.

The fifth theme, consisting largely of work in support of the other four, is the development of specific devices for use as research tools or in practical applications of energy sources. This theme encompasses projects running the gamut from very large to very small – from the design and building of particle accelerators to the construction of small detectors for nuclear radiation.

Under the direction of ERDA efforts in the last two themes have greatly expanded. Brookhaven is striking out in several new directions in support of Federal programs designed to help solve the nation's energy problems and alleviate the burdens placed on man's environment.

Almost all of the research at Brookhaven from its beginning has been relevant in some degree to problems of energy. Earlier the main thrust was a large effort in reactor technology which was a part of the Atomic Energy Commission's endeavor to develop atomic energy. Among other things the Laboratory designed and saw to the construction of three research reactors, and developed the concept of the liquid metal fueled reactor for power production. The Laboratory also made substantial research and development contributions in such

technical areas as reactor physics, reactor materials, including fuels, and heat transfer.

The AEC phased out its reactor technology program at Brookhaven in the period 1967-1972. At the same time, the Laboratory began to develop a series of new programs in energy, some funded by AEC and some by other agencies. These initiatives predated the "oil crisis" of 1973-1974 and the formation of ERDA in 1975. Thus, while the total Laboratory manpower declined 18% in the period 1970-1974, the fraction of the staff engaged in work in or directly related to energy technology rose from less than 1% in 1970 to 10% in 1974.

Since the formation of ERDA this component of the Laboratory program has grown. In fiscal year 1976 a diversified and substantial effort in energy and environment programs accounts for approximately 30% of the total Laboratory staff.

These energy programs can be conveniently described under four broad categories: Underlying Research; Environment and Health; Analysis and Support; and Technologies.

Work in the first category, Underlying Research, is somewhat arbitrarily designated from all the basic research at the Laboratory as basic research that has goals of direct significance to energy technology. As an example, research on properties of materials, where fundamental information on a substance is being obtained, is included in this group if the particular substance under investigation was chosen largely because of its importance for energy. Neutron diffraction determination of the structure of ionic solids of interest as electrolytes in batteries is a specific example. The program on fundamental properties of metallic hydrides is another. Some of the work in the biomedical area is also included.

The category Environment and Health covers work to determine the effects of energy production systems on all organisms, including man, and on the environment. It also includes the effects of pollutants arising from the principal uses of energy, as well as research and development on controlling pollution. Programs in coastal oceanography, meteorology and atmospheric sciences, land and fresh water environmental sciences, and pulmonary physiology and inhalation toxicology fall in this category.

Analysis and Support describes a wide variety of analytical studies related to systems for energy production, utilization, and conservation, as well as technical supporting work for ERDA, the Nuclear Regulatory Commission (NRC), and other federal agencies. Specific examples are the studies performed by the National Center for Analysis of Energy Systems; the work of the National Neutron Cross Section Center; activities of the Technical Support Organization which provides support to ERDA and NRC in their missions of preventing the diversion of special nuclear materials; the Biomedical and Environmental Assessment program; and the programs in Reactor Safety Evaluation and Research.

The Technologies category covers the development of specific energy-producing methods or systems, and components. This category is significantly different from the first three, whose support is a traditional government function. Projects in the technological area are focused on the more immediate problems of energy supply, utilization, and conservation, and bring Brookhaven directly into the national energy picture. The Laboratory is currently engaged in the development of magnetic fusion energy through the areas of fusion systems engineering, magnetic systems, fusion reactor materials, plasma heating by neutral beams, and the development of neutron sources for testing fusion reactor materials. Past and continuing programs in accelerator development and construction, superconductors and superconducting magnet development, materials technology, analysis of energy systems, hardware engineering, reactor safety analysis, and the construction of large complex research devices all contribute to the skills and manpower suitable for the growth of this program into one of major proportions and one that can make significant contributions to the national program in magnetic fusion energy.

Additional examples of programs in the Technologies category are the development of superconducting ac power transmission lines, the flash hydropyrolysis of coal, the development of a solar-powered steam system, the development of hydrogen-based energy systems, the development of radioactive waste storage materials and systems, and the development of various composite materials for such diverse applications as in underground mines (to ensure roof integrity), bridge pavements (for longer life under adverse environmental exposures), and geothermal technology (for well casings). Programs in this category will eventually be transferred to industry for final demonstration and use, as some have already been.

The general goals for the future are to contribute vigorously, broadly, and effectively to the national energy research and development effort, building on the strengths of the Laboratory and utilizing its special character, particularly its devotion to frontier science, its close coupling to the academic community, and its experience in working with industry.

* * * * *

Clearly it would be impractical to describe all the activities at the Laboratory in sufficient detail to be comprehensible; the sheer bulk of the report would deter any but the most resolute reader. Therefore only a few samples of the most significant research accomplishments of the last two years have been given.

Also the arrangement of the report has been altered in an effort to reduce repetition and make it more convenient for the reader. In the previous Highlights the major facilities were described first and then the research results by the various Departments of the Laboratory. This time each particle accelerator is covered in the section describing the research program of the Department which is the principal user. Thus the Tandem Van de Graaff comes under the Low Energy Nuclear Physics section, for example. And the section on High Energy Physics includes the work of the Accelerator Department, research at the Alternating Gradient Synchrotron (AGS) by university users, and the high energy portion of the BNL Physics Department program.

HIGH ENERGY PHYSICS

INTRODUCTION

The U.S. Energy Research and Development Administration (ERDA) is the special trustee for the national program in High Energy Physics. For many years High Energy Physics has been the largest program at Brookhaven. No more fundamental frontier exists in nature than the search for the basic building blocks of matter. This is the ultimate objective of the high energy physicists at Brookhaven in their search for new particles, their characteristics, and interactions. High energy physicists, accelerator physicists, and engineers are also involved in the design and construction of powerful particle accelerators such as the AGS (33 GeV) and the proposed ISABELLE (a 200 GeV Intersecting Storage Accelerator) which are the essential implements for their research. These endeavors have given rise to important technological spinoffs, such as pulsed superconducting magnets, improvements in high vacuum techniques, high current ion sources, advances in cryogenics, etc. And history has demonstrated that long-range benefits inevitably accrue from a deeper understanding of matter.

The research in high energy physics at Brookhaven is carried out by members of the BNL Physics Department, Visiting Scientists, and the BNL Accelerator Department, or (more often) by teams combining these groups. To give the reader an overall picture of the program it seemed better to collect the highlights in a single section rather than separating them by BNL department as has been done heretofore. The Alternating Gradient Synchrotron (AGS) supports a very large experimental program, some 80% of which is devoted to the activities of visiting experimenters, mainly from universities, but also from other National Laboratories and other countries. The high energy activities of the Physics Department are devoted to research using the AGS as the particle source, as well as other accelerators, such as the 400-GeV synchrotron at the Fermi National Accelerator Laboratory and the proton-proton intersecting

storage ring at CERN. The Accelerator Department is responsible for the operation of the accelerator and the experimental facilities including beam lines, bubble chambers, and experimental magnets. In addition the Accelerator Department carries on research and development work aimed at improving the overall AGS facility and in particular aimed as well at work toward major accelerator systems.

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PHYSICS DEPARTMENT HIGH ENERGY RESEARCH

INTRODUCTION

Man's quest for an understanding of nature has almost invariably led him to explain events of greater complexity in terms of hypotheses of greater simplicity, at least as far as his perception is concerned. Examples of this type of reasoning are Mendeleev's periodic table classifying the chemical elements, Mendel's laws of genetics, and in our own field Bohr's model of the atom which led to quantum mechanics.

In particle physics with a maze of scattering data, particle spectroscopy, and other experimental information, we have a complex situation. Therefore, it is appealing to look for as few elementary particles as possible with as simple and unified a dynamics as possible to account for their interactions. In recent years the quark model has received some favor, with perhaps four different types or "flavors,"* and a simple exact symmetry to explain the indistinguishability of doublets and triplets of quarks, which are the configurations necessary to explain the patterns of the observed particles. This exact symmetry is known as color invariance and will have to be respected by any dynamics that is put forward to explain the present quark model, which has been very successful in explaining the present maze of data in hadron spectroscopy.

Additional information is furnished by the deep inelastic experiments where the quarks act approximately like free particles, when they are bombarded by electrons, muons, and neutrinos at extremely high energies and momentum transfers. The electrons, muons, and neutrinos, called leptons, have no structure on the scale of the strongly interacting particles, hadrons. Leptons serve as excellent probes of the structure of hadrons. There is also another class of experiments involving hadron-hadron collisions at high energies, with single hadrons or groups of them produced at high momentum transfer. These experiments also serve to probe the hadron structure in another way. The spectrum of particles coming out and their multiplicities will also be important in deciding the final description in particle physics. Finally, decay modes of the hadrons and other related experiments will also be of value in establishing the quantum numbers and selection rules involved in the classification of these particles and their currents.

We now turn to the experimental program at Brookhaven and how it is relevant to this overall picture. We will discuss the significance of these experiments in relation to the above picture one at a time.

HADRON SPECTROSCOPY

The observation of the hadronic states, both stable and metastable, the classification of their masses, spin parity, and their quantum numbers with respect to some internal symmetry group will be important for the quark model. Specifically, we would like to know the number of quark types and their configurations, relative orbital angular momenta, and total spin states. There is substantial evidence that the mesons are combinations of a spin ½ quark and a spin ½ antiquark in the orbital angular momentum states 0 and 1; the baryons are combinations of three quarks with the symmetric combination in terms of internal symmetry, spin, and antisymmetric with respect to color symmetry. Therefore, the observation of states more complicated than the above, or the re-

*The "flavors" of the quarks refer to their internal quantum numbers; at the present time these internal quantum numbers are (at least) "up," "down," "strange," and "charm." These merely are labels which also serve to classify the observed hadrons. In contrast the "color" quantum number was invented primarily to allow for certain combinations of quarks that are observed in nature, namely, the colorless ones. The states with color are thought to be confined or non-observable in hadron physics.

peated absence of some of these states, might tell us what kind of dynamics is relevant to hadron physics.

One of the most noteworthy developments in the past few years is the discovery of the J(3105) spin parity 1^- "particle" by an MIT/BNL team, and independently by a SLAC group (who called it the Ψ). This was shortly followed by the discovery of additional "particles" or "resonances" at even higher energies. The interesting feature of these states and their associated excitations is the narrow width, $\Gamma(\sim 75$ keV), much smaller than typical hadronic widths of the order of 100 to 200 MeV. The popular interpretation of these new states is that they are associated with the bound state of charm-anticharm quarks.*If this hypothesis is indeed correct then there should be many other states associated with charmed quarks; namely, states which are spin zero analogues of the J/Ψ called the η_c. There should also exist many other states with charmed quark and ordinary antiquark, namely, charmed mesons, and also charmed baryons from the combination of three quarks one of which is charmed.

In two different experiments groups from BNL in collaboration with other universities completed a search for the η_c. The first collaboration studied the reactions

$$p+\bar{p} \rightarrow \Lambda \text{ (forward)} + \text{neutrals},$$

and

$$p+\bar{p} \rightarrow K^0 \text{ (forward)} + \text{neutrals}.$$

In these reactions a search was made for the two-body decay modes $\Lambda\bar{\Lambda}$ and $K^0\bar{K}^0$ of the η_c An upper limit was thereby obtained for the production cross section times branching ratio. In a second experiment a search was made for the peripheral production of the η_c by a BNL/Cal. Tech. group in the reaction $p+p \rightarrow \gamma+\gamma+X$. An upper limit of 0.5 nb was obtained for the production cross section times branching ratio for the $\gamma\gamma$ decay in the mass region of 3 GeV. In this same data sample copious production of $\eta \rightarrow \gamma\gamma$, $\eta' \rightarrow \gamma\gamma$, $\omega \rightarrow \pi^0\gamma$, $f \rightarrow \pi^0\pi^0$, and $A_2\pi^0\eta$ was found. Evidence was also found for the production of a state of mass 1950 decaying into $\pi^0\pi^0$($J^P = 4^+$).

Other more conventional hadron spectroscopy was completed using the Multi-Particle Spectrometer and included a successful search for a high mass K^* system in a reaction

$$K^-p \rightarrow K^*n$$
$$\hookrightarrow \bar{K}^0\pi^+\pi^-.$$

The mass spectrum obtained is shown in Fig. 1 which shows a clear new bump at 1700 MeV.

Data have also been analyzed on the total cross section measurements of K^- on protons and deuterons in the laboratory range from 400 to 1065 MeV. In addition to the well known $\Lambda(1690)$, $\Sigma(1765)$, and $\Sigma(1070)$ resonances, the data show indications of several new structures; with isotopic spin 1 and masses 1608, 1633, and 1715 MeV and isotopic spin zero at 1646 MeV. Also strong evidence for a π^+p state at 1646 MeV and width 219 ± 23 MeV was found. This state is interpreted as a Regge recurrence of the well established 1236 MeV state.

Another of the experimental groups, "The New Group," has also contributed greatly to this field in the way of an extensive analysis of the $K\omega$ spectrum from K^-p data taken at 7 GeV/c. Evidence of a new resonant state with mass and width 1710 MeV and approximately 110 MeV, respectively,

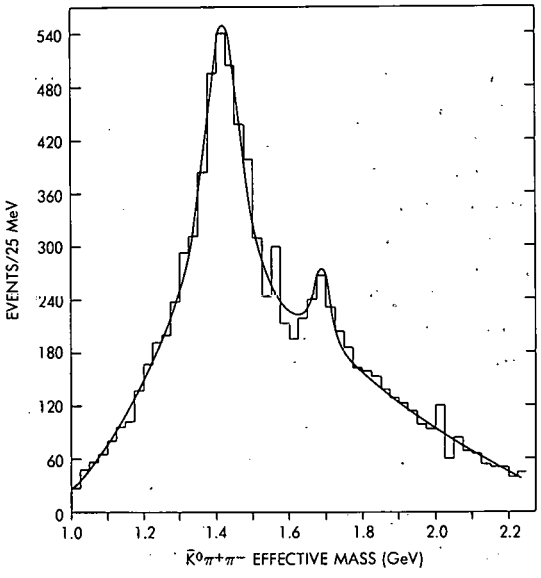

Figure 1. Distribution of the effective mass of the $\bar{K}^0\pi^+\pi^-$ produced in the reaction $K^-p \rightarrow \bar{K}^0\pi^+\pi^-n$ at 6 GeV/c. There is a very large peak at the mass of 1.42 GeV corresponding to a well known K^* resonance and a new peak at a mass of $1.692\pm.006$ GeV. These data were obtained with the BNL Multi-Particle Spectrometer.

*"Charm" is the name given to the fourth type of quark needed to form a suitable set of building blocks to explain the properties of "elementary" particles.

was presented. In another publication a full analysis of the $\pi\omega$ and the $K\omega$ systems was presented at a topical conference on meson spectroscopy.

Results on the single gamma decays of the η', ω', and ϕ mesons and the $\Xi^*(1535)$ baryon were reported. This analysis includes data from K^-p interactions at 2.18 GeV/c in the 31-inch bubble chamber. The mode $\eta' \rightarrow \pi^+\pi^-\gamma$ was detected and no charge asymmetry between $\pi^+\pi^-$ was observed to within a level of 10%. A search for the SU_3 allowed mode $\eta' \rightarrow \omega\gamma$ yielded an upper limit of 5% which is compatible with ~3% from theory. No $\pi^+\pi^-\gamma$ decays from the ω or ϕ mesons or $\Xi^-\gamma$ decays from the Ξ^* were detected.

A study of the K_L^0 decays utilizing the SLAC streamer chamber is in progress; the total sample of approximately 460,000 events was measured and processed. The analyses of the modes $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ and $K \rightarrow \pi\, e\nu$ are in the final stages. Information should be forthcoming on the form factors for the decay $K \rightarrow \pi l\nu$.

NEUTRINO INTERACTIONS

One of the areas alluded to earlier was the scattering of leptons (electrons, mesons, and neutrinos) on hadrons, as a probe for the structure and properties of hadrons. Perhaps the most novel probe is the neutrino; its interaction with matter is very small. A neutrino can go through large thicknesses of matter without appreciable interaction. In recent times the neutrino interaction has become very important to identify and to find the quantum numbers of the neutral currents that are essential for understanding the unified theories of weak and electromagnetic interactions. Most of the research by BNL groups involving leptons as a probe for hadron structure is centered around the neutrino interactions in hydrogen and deuterium in the few GeV range. The data came from the BNL 7-foot low temperature bubble chamber where approximately 120,000 pictures were taken this past year. The most astonishing result was the observation of one event that violated a long established selection rule $\Delta S = \Delta Q$ (S = strangeness, Q = charm). This probably constitutes the first observation of a bare charmed particle, namely Σ_c and Λ_c baryons. Other findings included a value of the ratio of the neutrino-neutron to the neutrino-proton cross section of 1.48 ± 0.17 in reasonable agreement with quark model expectations.

The neutrino group at BNL is also preparing to begin a high energy neutrino experiment using the 15-foot bubble chamber at Fermi National Accelerator Laboratory. The primary objective of this experiment is the study of interactions of neutrinos leading to final states containing lepton pairs.

Other experiments on weak interactions, primarily on the rare decay modes $K_L^0 \rightarrow \pi^+\pi^-\gamma$ and $e^+e^-\gamma$, are being done by a BNL/Rochester University collaboration. A branching ratio on the mode $K_L \rightarrow e^+e^-\gamma$ and an upper limit for $K_L^0 \rightarrow \mu^+\mu^-\gamma$ should be obtained this year.

INCLUSIVE HADRONIC EXPERIMENTS

A collaboration between a BNL, Cal. Tech., and Berkeley group has reported on large transverse momentum π^0 from the reactions $pp \rightarrow \pi^0 + X$ and $\pi p \rightarrow \pi^0 X$. This experiment was completed at Fermi National Lab, using the 100 to 200 GeV pion and proton beams; the π^0 comes out near 90° in the center of mass system. These data are of interest in confirming some of the constituent quark models at large transverse momentum, where the hadron structure is important.

Another set of experiments was performed at Fermi Laboratory by a BNL/Yale collaboration to explore the production of muons which had been observed elsewhere at 10^{-4} of the pion rate with large transverse momentum. The muons at this level at large transverse momentum are called prompt muons. It is interesting to determine whether their source is the electromagnetic decay of a vector meson or otherwise.

THEORETICAL PHYSICS

The research of the Theory Group ranged from an analysis of fundamental theories of hadron physics to phenomenological studies of models and their relation to experiment. In the former category there has been continued interest in the structure of extended objects, i.e., hadrons such as protons, and quark confinement theories. If the quarks really are not observed in the laboratory then there will be continued necessity to have them confined within the hadron. One particular scheme is the "bag model" of the MIT groups. In this connection a method was developed to make this class of models into a satisfactory quantum theory.

In another area a thorough study of a quantum mechanical system was presented where both confinement channels and scattering channels were present in the same Hamiltonian. The two different types of channels were allowed to communicate via a well behaved interaction; several rigorous results were established.

In more phenomenological areas there were a number of different pieces of research completed. In the area of charmed particle and W boson production we have the following results:

a) A quark description of currents was developed and applied to the production of charmed particles by neutrinos. This model is consistent with the events observed in high energy ν and $\bar{\nu}$ reactions if the decays of the charmed particles involving leptons are greater than 10%.

b) Within a well specified quark proton model the rates for W boson production were estimated for the range of energies relevant to ISABELLE, the storage ring accelerator proposed by Brookhaven in which 200 GeV protons collide head on with 200 GeV protons moving in the opposite direction, thus achieving 400 GeV energy in the center of mass system.

c) The recently discovered J (or ψ) particle was incorporated into a dual model description of pp and np elastic scattering giving a good fit with a small number of parameters.

Again in the spirit of the dual model the Ψ' (3.684) and Ψ''' (4.415), recently observed excited partners of the J/Ψ system, were assumed to be daughters of Regge recurrences. Then within the complex structure seen in e^+e^- annihilation near 4.1 GeV there is predicted to be a narrow resonance near 4.103 GeV.

d) Two-body nonleptonic decays of charmed pseudoscalar mesons have been calculated in models with the most general structure for right handed currents. The implication of the upper bounds for $D \rightarrow K\pi$ obtained in the SPEAR charm search are discussed in this model.

In the area of Reggeon phenomenology the following results were obtained:

a) An analysis of the Reggeon cuts in inclusive production processes for hadron-hadron collisions was completed. The result of this analysis is that it is difficult to obtain information about Reggeon cuts in inclusive processes without making additional assumptions about the analytic structure of the amplitude.

b) In another work it was possible, under reasonable assumptions, to calculate at least a part of the Reggeon cut that does not depend on the details of the Reggeon-Reggeon amplitude. This has been applied to the charge exchange reactions $\pi^-p \rightarrow \eta X$ and $K^-p \rightarrow K^0X$ and the cut contributions are found to be small.

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RESEARCH BY VISITING SCIENTISTS

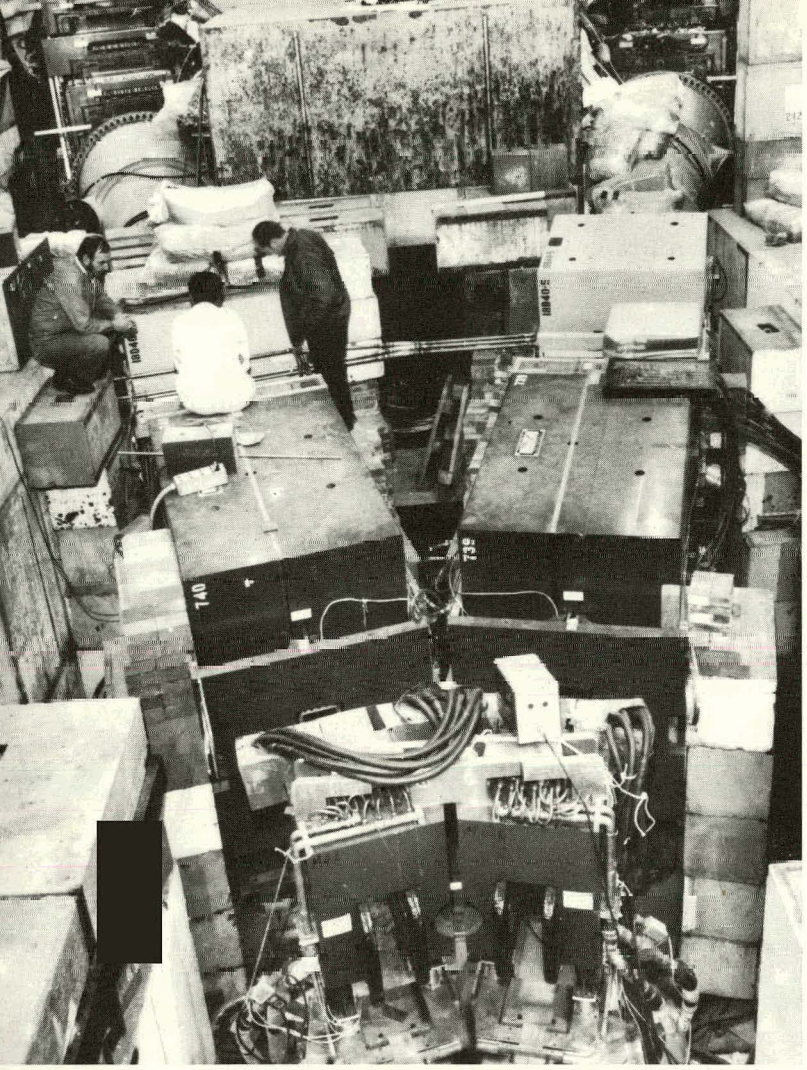
Only a few examples of the diversified research program at the AGS will be mentioned.

In November 1974 one of the major discoveries in high energy physics was announced at Brookhaven and at the Stanford Linear Accelerator Center. It was the observation of the now celebrated J/ψ particle. The J particle has a mass of 3100 MeV and a very long (by nuclear standards) lifetime, $\sim 10^{-20}$ sec, so that the width of this resonance is of the order of 70 keV. Both the mass and this narrow width were unexpected properties. Here at Brookhaven the MIT/BNL team headed by Prof. S.C.C. Ting* discovered the J particle using a sophisticated double-arm spectrometer that identified an e^+ and an e^- from the decay. The spectrometer is shown in Fig. 2. Figure 3 illustrates the strikingly sharp mass peak in the e^+e^- spectrum. An explanation for the properties of the J/Ψ particle was soon given in terms of a charm quark and an anti-charm quark structure. Ramifications of the J/Ψ and subsequent discoveries are still being actively pursued by experimenters and theorists everywhere.

A topic of very great current interest is the direct production of leptons in hadron-hadron collisions. Generally speaking, it has been found that the ratio of lepton to pion production is of the order of 10^{-4}.

A University of Pennsylvania/State University of New York, Stony Brook collaboration recently completed measurement of the cross section for

*NOTE ADDED IN PROOF. In October 1976 the Nobel Prize in Physics was awarded to Professor Ting and Professor Burton Richter of Stanford for this discovery.



← Figure 2. The double-armed spectrometer used by the MIT/BNL group to discover the J particle. A 30 GeV proton beam from the AGS struck a beryllium target which was located just below the bottom of the photograph. Each of the two 21-m long arms has magnets and detection devices to identify and measure the energies of the electron and the positron from the decay of the J particle.

directly produced positrons. They used a magnetic spectrometer in which the positrons were identified by lead glass Cerenkov counters. Prompt positrons were observed near 90° in the center of mass. For $p_\perp$ in the range 0.8 GeV/c to 1.5 GeV/c they concluded that vector meson decays may be sufficient to account for the number of prompt positrons; for $p_\perp < 0.8$, however, they observed a significant excess. At the lowest $p_\perp$ measured, the ratio of prompt electrons to π^- was greater than 10^{-4}. Beam momenta of 10, 15, and 24 GeV/c were used, and no threshold effect in prompt positron production was found over this interval.

A "conventional" (i.e., non-charm) new-particle search has been performed by a Stanford group which undertook a search for highly relativistic Coulomb-bound $\pi^\pm\mu^\mp$ states. These atoms have been calculated to be formed with a branching ratio of 10^{-7} in the decay $K_L^0 \rightarrow (\pi\mu)_{atom} + \nu$. The major objective of the experiment was to explore possible anomalous short-range π-μ interactions. The atomic beam is derived from a proton beam

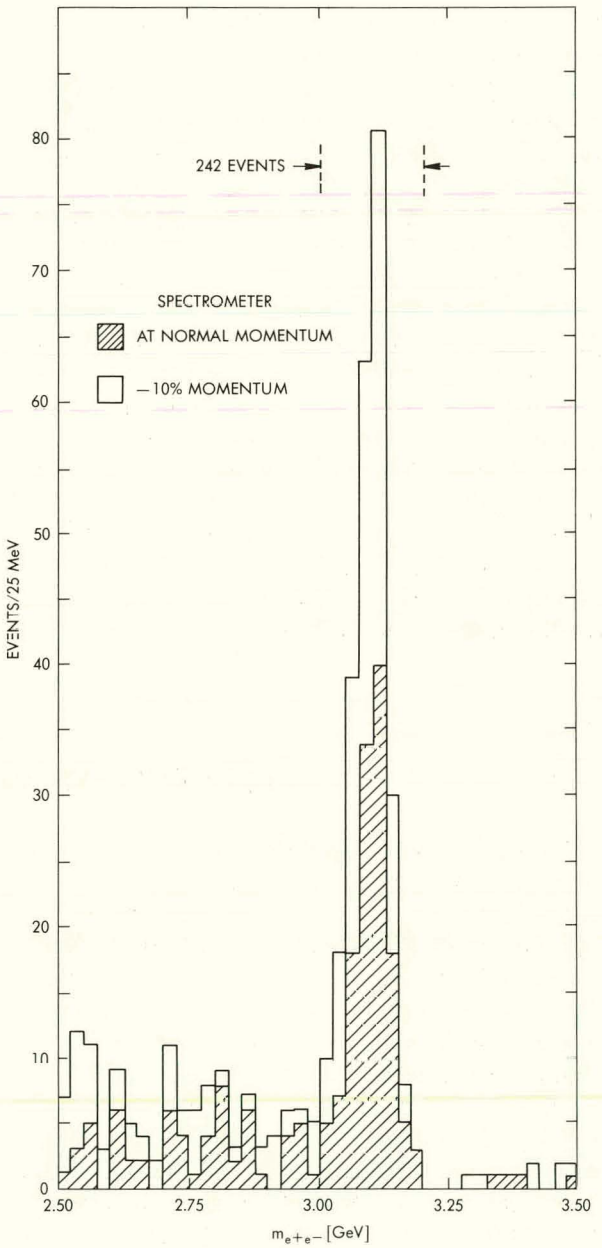


Figure 3. The effective mass plot of electrons and positrons detected by the apparatus of Fig. 2. The large number of pairs with an effective mass at 3.1 GeV relative to the other masses is the signature of the J particle.

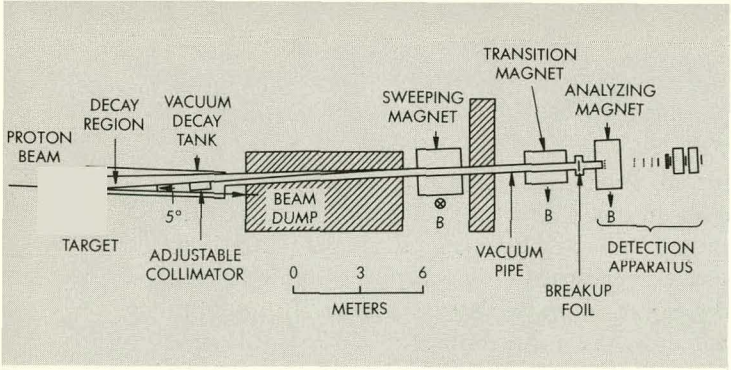


Figure 4. Plan view of the beam line used to produce $\pi\mu$ atoms in K_L^0 decay. The adjustable collimator shields the detection apparatus from a direct view of the target.

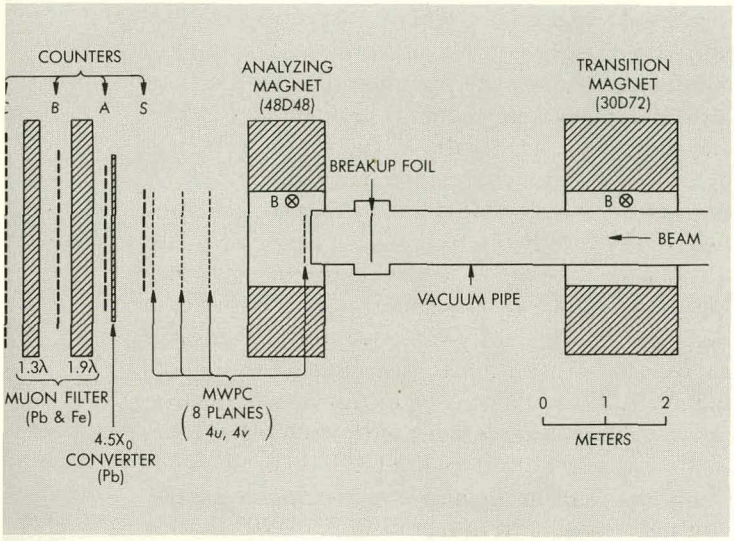
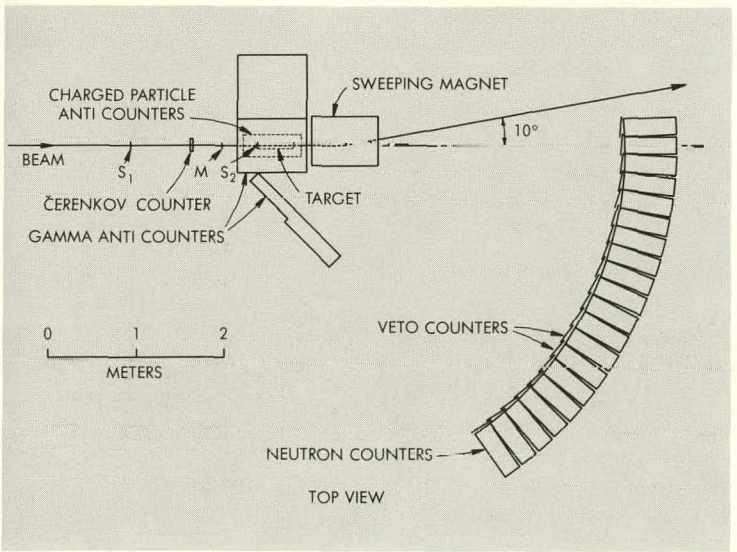


Figure 5. Elevation view of the $\pi\mu$ detector.



ıre 6. Apparatus used to study K−p charge exchange.

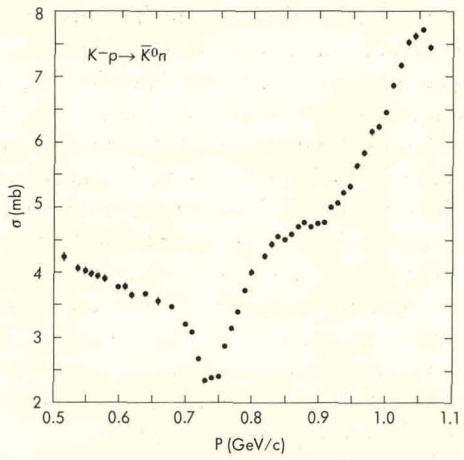


Figure 7. Preliminary cross sections for the reaction $K^-p \rightarrow K^0n$.

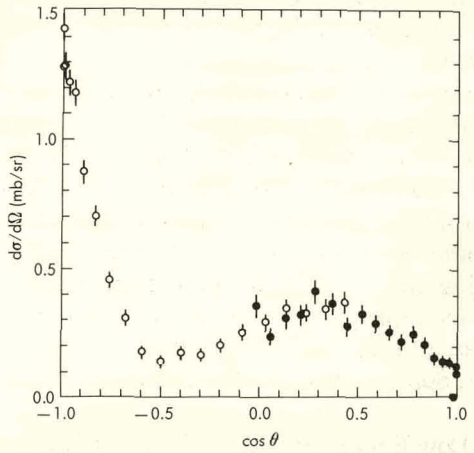


Figure 8. Preliminary and uncorrected differential cross section for the reaction $K^-p \rightarrow K^0n$ at a momentum of 877 MeV/c. Open squares are cross sections derived from events occurring at a time-of-flight corresponding to K_L^0 while crosses are from events occurring at a time-of-flight for neutrons.

which strikes a Be target. Kaons from this target decay in vacuum (Fig. 4). The decay products travel 15 m to the detection apparatus. Most of the charged particles are filtered from the beam by two magnets. The technique for observation of the atoms is their dissociation in a thin foil (Fig. 5). The atomic beam is expected to be largely composed of ls states bound with 1.6 keV energy. This is the most tightly bound state but dissociates readily in a few tens of milligrams of material. Thus, in order to allow an investigation of the breakup fraction dependence on foil thickness, the

foils are placed inside the vacuum. The dissociated π and μ travel in parallel until they separate on entering an analyzing magnetic field. At the point where the separation is greater than 1 cm, the vacuum chamber ends and a Multi-Wire Proportional Chamber (MWPC) records the coordinates on exit. The topology of the $\pi\mu$ atom is very distinct: a muon and pion emerging from the break-up foil precisely in parallel, coincident in time, and with identical velocities. This latter characteristic gives the equality $p_\mu/p_\pi = m_\mu/m_\pi$. The experiment has achieved a clear signal which heralds the first atomic system observed in the decay of an elementary particle. The bulk of the data has been taken with a 0.76 mm Al foil and an early analysis indicates a dozen events with a background of half an event. The signal rate appears to be substantially lower than expected, assuming a branching ratio of 10^{-7}, but a quantitative discrepancy will be determined only after a detailed analysis.

A group from Lawrence Berkeley Laboratory is also studying the low energy $\bar{K}N$ system via the charge exchange $K^-p \rightarrow \bar{K}^0N$. The overall experimental arrangement, utilizing a large neutron counter array, is shown in Fig. 6. Running only with counters in the intense C2 beam, they are improving the world's data on the differential cross section by approximately an order of magnitude, which should significantly aid the Y* phase shift analysis. Some of their results are shown in Figs. 7 and 8.

The Low Energy Separated Beam (LESB) has produced several measurements of x-rays emitted in the cascade of negative kaons, sigma hyperons, and antiprotons through atomic states ending in their eventual capture in the nucleus. Two groups have performed three experiments in which the magnetic moments of the Σ^- and antiproton were determined from the fine structure splitting of the x-rays, the masses of the K^-, Σ^-, and $\bar{p}$ were obtained, and calculations of dynamic quadrupole mixing in exotic atoms of ^{238}U were verified.

Two developments have made measurements of this type possible: high intensity separated beams of low momentum kaons and antiprotons, and solid state detectors of high intrinsic resolution (typically 1 keV). The LESB is the best of its kind available and, in particular, the flux of low momentum antiprotons (several hundred stopping per pulse) is unique. For the Σ^-, measurements of the magnetic moment are limited by detector resolution, since the largest fine structure splittings measured are less than 500 eV. A broadening rather than a splitting of the x-ray lines is observed, necessitating a computer dipole fit using the experimentally determined resolution of the detector. For antiprotons, the 1.9 keV fine structure splitting of the $n = 11 \rightarrow 10$ transition in ^{238}U was resolved by both groups. The Yale/Columbia apparatus is shown in Fig. 9. The apparatus used by the William and Mary/Virginia Polytechnic Institute/Carnegie-Mellon/Wyoming/Cal. Tech. group was similar. The Yale/Columbia Σ^- Pb, $n = 12 \rightarrow 11$ and $\bar{p}$U, $n = 11 \rightarrow 10$ spectra are displayed in Figs. 10 and 11, respectively. The results of both experiments are presented in Table I. The results of the two experiments are consistent with one another but the results for the Σ^- moment are nearly two standard deviations from the SU(3) prediction. Nevertheless, the consistency of the two results and their agreement with $\mu_{\Sigma^-} = (-2.1 \pm 0.8)\ \mu_N$ of Cool *et al.* which is predicted to be equal to μ_{Σ^-} by SU(3) is suggestive. Neither experiment is sufficiently sensitive to the intensity ratios in Σ^- transitions to distinguish the sign of the magnetic moment. The antiproton moments are in excellent agreement with each other and with $-\mu_p$ as required by the CPT theorem. The Columbia/Yale group also used the kaonic x-rays emitted consequent to stopping 2.8×10^9 K^- in Pb to determine the kaon and sigma masses. The fitted masses are given in Table II. The value of the antiproton mass is more than two standard deviations low compared to the known mass of the proton.

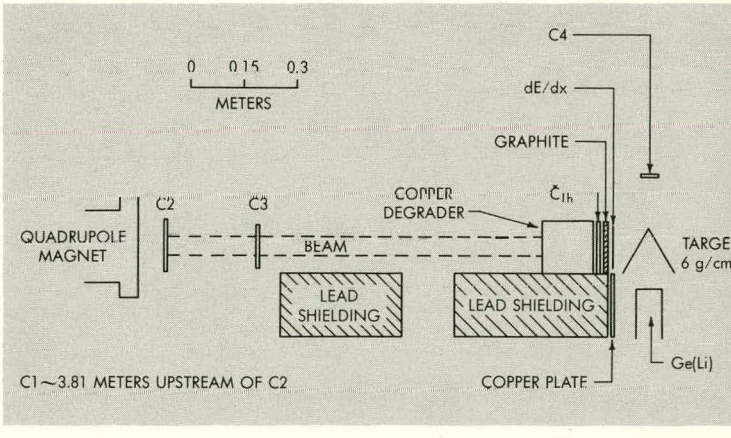


Figure 9. Apparatus used by Yale/Columbia group to measure x-rays from exotic atoms.

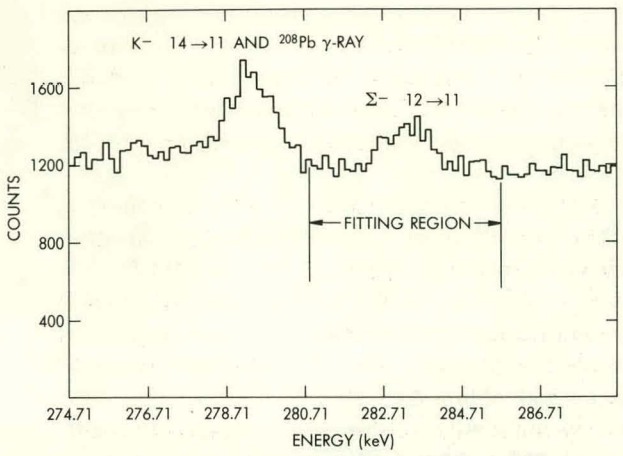


Figure 10. X-ray spectrum for $\Sigma^- n = 12 \rightarrow 11$ transition in lead, used to obtain Σ^- magnetic moment and mass.

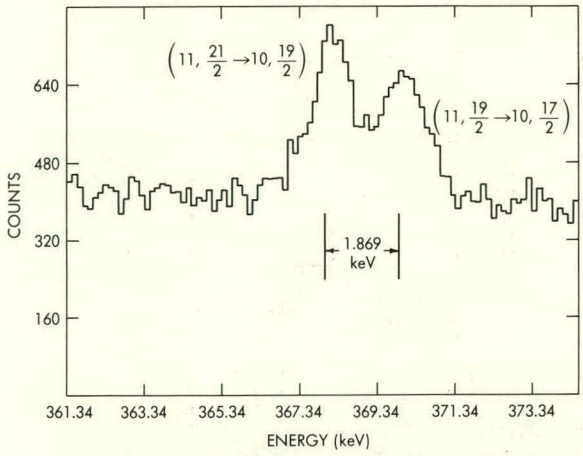


Figure 11. Two $n = 11 \rightarrow 10$ transitions of the antiproton-uranium atom, barely resolved by the Ge(Li) detector used by the Yale/Columbia group.

Table I

Magnetic Moments

Quantity	William and Mary/VPI/ CMU/Wyoming/Cal Tech/BNL	Yale/Columbia	SU(3) prediction
μ_{Σ^-}	$(-1.89 \pm 0.47)\ \frac{eh}{2m_{\Sigma^-}c}$	$-1.79\ ^{+.52}_{-.35}\ \frac{eh}{2m_{\Sigma^-}c}$ or $0.83\ ^{+.36}_{-.51}\ \frac{eh}{2m_{\Sigma^-}c}$	$-1.12\ \frac{eh}{2m_{\Sigma^-}c}$
$\mu_{\bar{p}}$	$(-2.819 \pm 0.056)\ \mu_N$	$(-2.791 \pm 0.021\ \mu_N$	$+2.793\ \mu_N$ (value of μ_p)

Table II

Particle Masses

Yale/Columbia	Accepted mass	Previous exotic atom result
M_{K^-} 493.668±0.014 MeV	493.715 ±0.037 MeV	493.691±0.090 MeV
M_{Σ^-} 1197.24 ±0.14 MeV	1197.35 ±0.06 MeV	
$M_{\bar{p}}$ 938.155±0.053 MeV	938.2796±0.0027 MeV*	938.3 ±0.5 MeV

*Proton mass.

After the discovery of weak neutral current interactions in inclusive neutrino interactions, two counter experiments were set up at the AGS to study exclusive channels of this interaction. Since the rates for exclusive channels may be more readily calculated than the rates for inclusive channels, these measurements will be important in determining the space-time structure of the weak neutral current.

A Columbia/Illinois/Rockefeller collaboration used a detector consisting of 21 modules of 1.83 meter-square narrow gap aluminum spark chambers (used originally in the two-ν experiment) interposed with scintillation counters and five 2.44 meter-square range chambers. They have reported preliminary results for the reactions $\nu n \rightarrow \mu p \pi^0$, $\nu n \rightarrow \nu n \pi^0$, $\nu p \rightarrow \nu p \pi^0$. These reactions are important in determining the I-spin structure of the

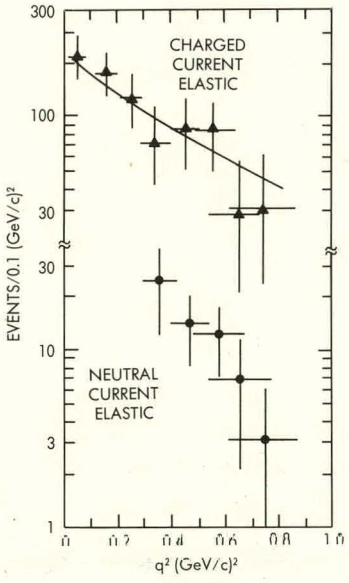


Figure 12. The distribution dN/dq^2 for $\nu n \rightarrow \mu^- p$ and $\nu p \rightarrow \nu p$. The solid curve is the calculated q^2 distribution for $m_A{}^2 = 0.9$ GeV/c², $m_V{}^2 = 0.71$ GeV/c².

weak neutral current. More recently they have reported the observation of neutrino elastic scattering from protons, $\nu p \rightarrow \nu p$. They have measured the rate relative to the quasi-elastic reaction $\nu n \rightarrow \mu^- p$ to be 0.25 ± 0.12, for $0.3 < q^2 < 1.0$ $(GeV/c)^2$.

A Harvard/Pennsylvania/Wisconsin group has also observed neutrino-proton elastic scattering. They obtain $\sigma(\nu p \rightarrow \nu p)/\sigma(\nu n \rightarrow \mu^- p) = 0.17 \pm 0.05$ for $0.3 < q^2 < 0.9$ $(GeV/c)^2$. The q^2 distribution of their data is shown in Fig. 12. Their apparatus consists of 12 calorimeter modules containing 30 metric tons of liquid scintillator. The experimenters use the outer edges of this volume as an active neutron shield. In a later experimental run this group also has observed antineutrino-proton elastic scattering under similar q^2 conditions. The neutral current to charged current ratio $\sigma(\bar{\nu} p \rightarrow \bar{\nu} p)/\sigma(\bar{\nu} p \rightarrow \mu^+ n)$ was measured to be 0.2 ± 0.1.

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ACCELERATOR DEPARTMENT

INTRODUCTION

The operation, maintenance and improvement of the Alternating Gradient Synchrotron (AGS), and the design, fabrication and operation of equipment required for the experimental program, are two of the major Department functions. The Department also provides experimenters with other large facilities including the 7-foot bubble chamber, the Multi-Particle Spectrometer (MPS) and a large computer complex, the On-Line Data Facility (OLDF). Another major effort is the design and prototype construction of the proposed Intersecting Storage Accelerator (ISABELLE) which will use superconducting magnets.

In conjunction with the Department of Applied Science the Accelerator Department is working on a prototype superconducting electric power transmission line.

AGS DIVISION

Over the past ten years the AGS has been continuously improved and gradually transformed into a high-intensity proton facility with a fast external beam system and a slow beam extraction system that supplies protons to three or more external targets simultaneously. A peak beam intensity of 1.09×10^{13} protons/pulse has now been obtained and the accelerator runs routinely with beam intensities of $\approx .85 \times 10^{13}$ protons/pulse (Fig. 13). Due to the unique combination of a high machine cycle rate and high intensity, 0.4×10^{20} protons have been accelerated in a single year. The facility is capable of handling a large number of high-energy physics experiments simultaneously. The use of on-line computers is rapidly being implemented for more sophisticated and efficient operation.

LINEAR ACCELERATOR INJECTOR

The 200-MeV proton linear accelerator (linac) performs as an injector for the AGS and as an isotope production facility (BLIP). A new accelerating column was installed in the Cockcroft-Walton preinjector, replacing one with a history of technical problems. Steering of the 750-keV proton beam from the preinjector to tank 1 was improved. New rf pick-up probes were installed in the linac tanks in an effort to reduce vacuum failures. A new type of tube was installed in the rf modulators to improve system reliability.

In addition to serving as an injector for the AGS, the linac serves satellite programs using the Brookhaven Linac Isotope Producer (BLIP) and the Chemistry Linac Irradiation Facility (CLIF). In order to increase reliability the transport line to these facilities was completely rebuilt. Neutron-rich isotopes are being studied with use of both primary proton and secondary neutron bombardment schemes.

Radioisotopes are produced on a regular weekly basis for use in clinical studies in various research hospitals. A new, low intensity, 200 MeV beam line is being constructed to investigate the possibility of proton irradiations for therapeutic purposes.

Accelerator Modifications

A new pick-up electrode system was commissioned. The system, which gives beam position to within 0.2 mm, is tied to the on-line computer and allows the measurement and plotting of the horizontal and vertical orbits.

The Ionization Beam Scanner built by CERN was installed in the AGS ring and made operational. This device provides continuous information on the density distribution of the circulating protons and is a valuable diagnostic tool.

A new low level ring rf system was built and installed. This unit not only provides more flexibility in the capture process, but also allows routine operation of the slow external beams with rf structure present.

Modifications to the 13° injection and inflector magnets have improved the injected beam intensity.

External Beams

An instrumentation system was installed in each of the four slow extracted beam (SEB) lines to provide experimenters with more information on beam intensity, position, and shape. Seven instrumentation stations were fabricated to provide electronic processing of the beam information. This information is forwarded to the computer as well as to user displays.

All the SEB transport power supplies were modified for control and monitoring by the AGS computer. Computerization of all the fast extracted beam (FEB) extraction and transport power supplies and diagnostic equipment was completed. A new external beam console was built to consolidate all of the FEB and SEB beam controls and monitoring (Fig. 14). Many items, e.g., power sup-

Figure 13. Operations personnel at AGS Main Control Room console when 10^{13} protons/pulse were first achieved.

Figure 14. New external beam console in AGS Main Control Room which combines the control functions for both slow and fast external beams.

plies, multiplexers, etc., not normally adjusted during routine operation, were removed from the Main Control Room. The orthogonalization computer program for external beam transport power supplies was brought into operation. This program automatically adjusts the appropriate power supplies when a change of sharing ratios between primary beam target stations is desired. By simplifying the task of the Main Control Room operator, user requirements were satisfied expeditiously and set-up time reduced.

By repositioning the H10 extraction magnet, and providing fast orbit deformation about this extraction magnet, significantly higher beam intensities were extracted in the FEB line. Intensities as high as 0.9×10^{13} protons/pulse were delivered to the target in the North Experimental Area.

Computer Control of the AGS

The room housing the AGS control computers was enlarged and 64,000 words of memory, a disk, and a set of fast registers were added to the central PDP-10. A link to the On-Line Data Facility (OLDF) was brought into operation so that one of the OLDF PDP-10 computers can reload the AGS peripheral processors in case of an AGS PDP-10 failure. Additional PDP-8 links to the PDP-10 computers were provided to accommodate the increasing number of devices being controlled and monitored by the computer system.

Programs were written and implemented to provide information on machine performance on a pulse to pulse basis. This includes FEB/SEB extraction and transport efficiencies, intensities, sharing ratios, etc.

Keyboard/track ball modules were provided in the external beam and injection consoles to provide easy access for control and monitoring of computer-controlled devices.

High-Intensity Negative Ion Beams

The interest in production of intense negative hydrogen ion beams arose from possible applications in high-energy accelerators and fusion reactors. For accelerators and storage rings negative ions (using the multiturn charge-exchange injection scheme) offer an alternative to the present proton injection scheme. This could result in a higher phase-space density of the injected beam. The required beam currents would be several tens of milliamperes. For some fusion devices, e.g., toroidal Tokamaks, intense negative beams may be used for neutral beam production and subsequent plasma heating. This may require beam currents as high as several tens of amperes.

Early in 1973 a program was started at BNL for development of an operating source of negative hydrogen ions to replace the present proton source in the AGS preinjector. Some time later funds were received to support work on high-intensity sources for applications in fusion devices. Prototypes of two different sources were built, a hollow discharge duoplasmatron and a magnetron source. Best results were obtained when sources were operated with a mixture of hydrogen gas and cesium vapor. Currents up to 50 mA were obtained from the duoplasmatron source and above 500 mA from the magnetron source. While an improved version of the duoplasmatron will satisfy the requirements for injection into the AGS, the emphasis will be on the further development of magnetron sources. These are more likely to yield beam currents of negative ions adequate for fusion applications.

EXPERIMENTAL PLANNING AND SUPPORT DIVISION

The experimental planning involved in operating a high-energy physics program at the AGS requires an efficient program for bringing the accelerated protons to a number of primary beam targets. The secondary particles produced therein by high-energy collisions must then be transported to the various experimental setups in such a way as to satisfy the requirements of a large number of experiments simultaneously. The diversity of these requirements is reflected in the different types of secondary beams delivered to experimenters. These include charged-particle and uncharged (neutral) beams, high-resolution beams in which the momentum is precisely established, and "separated" or, more accurately, "purified" beams in which one type of secondary particle, normally present in relatively small numbers, is greatly enhanced. In addition, the time duration of the delivery of secondary particles to the experimenter can vary from microseconds, for experiments in which data are taken photographically in a limited sensitive time (e.g., bubble chamber), to one second for experiments that detect particles by electronic means. The latter experiments, which use detectors such as scintillation counters, spark chambers, or proportional chambers, operate most

efficiently when the events to be studied occur at a uniform rate.

As experiments are concluded and new ones proposed, the configuration of beams and experiments is a dynamic one and the floor plan is frequently modified. The configuration of the experimental area in January 1976 is shown in Fig. 15.

The support given experiments involves construction and operation of the components of the beam transport, experimental targets (frequently liquid hydrogen or deuterium), and provision of analyzing magnets, modular electronic logic, and floor space, including house trailers for operation of the required electronics. Services include survey, electrical power, cooling water, vacuum, and installation of large components of the experiment requiring professional rigging.

EXPERIMENTAL PROGRAM

Naturally, the experimental program of the past two years was strongly influenced by the startling discovery of the J particle in November 1974 made by a joint MIT/BNL experimental group led by Professor Ting of MIT (see section on Research by Visiting Scientists). The pair spectrometer built by the MIT/BNL group has been utilized in a number of different ways in searching for further manifestations of charm. Ten additional experiments among those listed in Table III were quickly adapted for searches for particles of a similar nature. The inherent flexibility and adaptability of the experimental area layout and schedule enabled all of these changes to be carried out within one or two months of the announcement of the discovery. The first direct observation of charm may have occurred in an experiment by a BNL group using the 7-foot bubble chamber in a neutrino beam.

Further indication of the diversity of the experimental program can be seen in the layout of the East Experimental Area (Fig. 15). Of the twelve experiments shown set up during December 1975, nine experiments were using protons from the AGS simultaneously. Averaged over the year, the number of simultaneously operating experiments is 7 – 8 in the East Area. This number is kept as high as is practical by appropriate scheduling so that the limited electrical energy and other basic resources can be used as efficiently as possible. Alternating with the East Area where the general counter and spark chamber program is carried out with the use of a one second long spill from the AGS, is the neutrino physics program in the North Area (Fig. 15) which utilizes a more rapid AGS cycle and a three microsecond spill.

Figure 15. Experimental area layout at the AGS during January 1976.

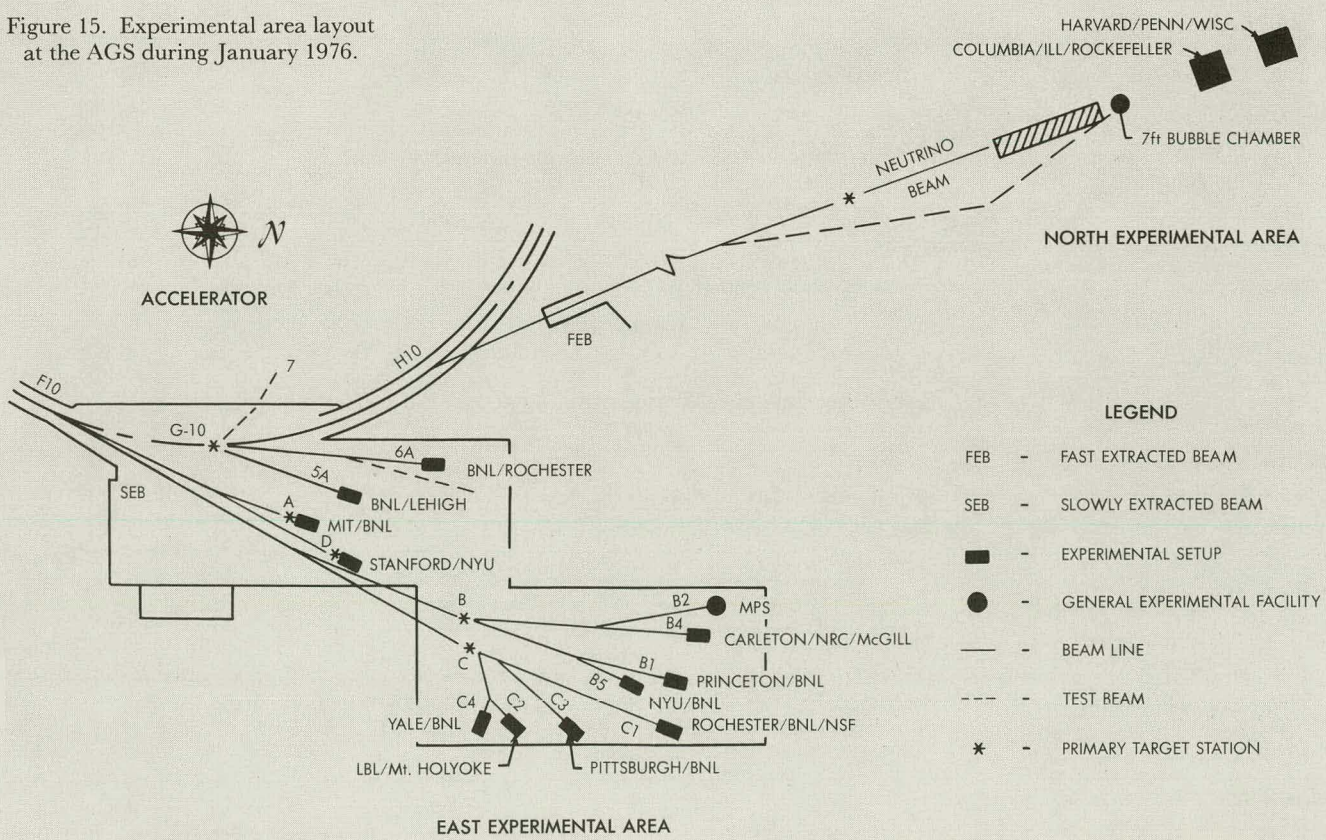


Table III

High-Energy Physics Experiments at the AGS
July 1974 – June 1975

A Target Station

A, Primary Proton Beam

#598	MIT/BNL	$\pi^+\pi^-$, K^+K^-, e^-e^-, $\bar{p}p$ mass spectra in the 1.5 to 5 GeV/c^2 region.
#669	MIT/BNL	Production and decay of J particle and charmed particles.
#675	MIT/BNL	Measure inclusive cross sections of single particles and of identical particles closely produced in phase space.

B Target Station

B1, High-Energy Charged Beam

#635	U. Penn	Cross sections in projectile fragmentation region.
#650	U. Penn/SUNY	Single electron production in proton-proton collisions.
#661*	Princeton/BNL	Antiproton-nucleon interactions and search for charmed objects.

B2, Medium-Energy Separated Beam – 2 to 6 GeV/c, 2 to 9 GeV/c $\bar{p}$

#557	Brandeis/Mass/Penn/BNL	Properties of boson resonances.
#594*	BNL/CCNY	Production and decay of boson resonances.
#596*	CMU/SMU	$\bar{p}p$ annihilation, exotic exchange, and other reactions from 4-10 GeV.
#601	Brandeis/Syracuse	$\bar{p}p \rightarrow V^0 + V^0 +$ neutrals near 6 GeV/c.
#654	MPS	Production of charmed particles in $\bar{p}p$ reactions.

B4, East Branch of Medium-Energy Separated Beam

#546	Carleton/McGill/NRC	Examine the K*(1420) mass region for fine structure and splitting.

B5, Neutral Beam

#597*	Princeton/U. Mass.	Study of the decay, $\Lambda \rightarrow p + e^- + \bar{\nu}$.
#615	NYU/BNL	Precision measurement of the phase and magnitude of CP violating parameter η_{00}.
#626	Syracuse/BNL	Production and annihilation of antineutrons.

C Target Station

C1, Muon Beam – 12 GeV/c

#632*	Rochester/BNL	μ nucleus interactions at 12 GeV/c.

C2/C4, Low Energy Separated Beam 0.5 to 1.1 GeV/c

#524	Yale/BNL	$K^{\pm}p$ polarization parameter, 650-1087 MeV/c.
#548	Princeton	Precision study of the decay $\Sigma^- \rightarrow ne^-\nu$ to determine the sign and magnitude of the form-factor ratio g_A/g_V.
#574	VPI/W&M/Wyo/CMU	$K^-\Sigma^- + \bar{p}$ mass; $\Sigma^-\bar{p}$ magnetic moment.
#634	LBL/Mt. Holyoke/CERN	Search for Y* from K^-p charge exchange.
#641*	BNL/Case	Polarization K^+n elastic scattering, 0.7-0.9 GeV/c.
#643*	W&M/VPI/CMU/Wyo/CIT	X-ray transitions from stopped $\bar{p}$, K^- in H_2, He.
#655	Syracuse/W&M/BNL	Search for bound states of $\bar{p}p$ systems by γ-ray emission spectra.
#662	Yale/BNL	Measure $d\sigma/d\Omega$ for $\bar{p}p \rightarrow \pi^+\pi^-$, K^+K^-, $\bar{n}n$, $\bar{p}p$.
#666	LBL/Mt. Holyoke/CERN	Measurement of $\bar{p}p \rightarrow \bar{n}n$ total cross section.

C3, Hyperon Beam, 23 GeV/c Σ^-, Ξ^-, Ω^-

#583	Pittsburgh/BNL/Mass	Study of Y* resonances produced in hyperon-nucleon collisions.
#618	Pittsburgh/BNL	Study of Ξ^- leptonic decays and some related physics.

D Target Station

D, Primary Proton Beam

#614	Stanford/NYU	$\pi^-\mu$ atom search, Lamb shift.

Internal Target at G10

Beam 5A, 1-3 GeV/c Electrostatically Separated Beam

#660	Syracuse/BNL	Bound states of $\bar{p}p$ system by γ ray emission spectra in $\bar{p}$-p annihilation
#664	BNL/Lehigh	Hypernuclear γ-rays.

Beam 6A, Neutral Beam

#631	Rochester/BNL	Radiative decay of K_L^0.
#656	Rochester/BNL	Search for narrow $\bar{p}p$ & $\bar{p}p\gamma$ states.

External Target in Fast Extracted Beam

U1 Line, Neutrino Beam

#427*	BNL	Bubble chamber study of neutrino reactions in deuterium.
#532*	Wisconsin	A study of antineutrino interactions on protons.
#605	Columbia/BNL/Rockefeller/Illinois	Study of the neutral current in the leptonic and semi-leptonic processes induced by high energy neut
#613*	Harvard/Penn/Wisconsin	Search for weak neutral currents at level of electromagnetic form factor of the neutrino.
#629*	BNL	Search for neutral currents from $\nu_\mu + p$ (or n) $\rightarrow \nu_\mu +$ hadrons (inelastic).
#652*	Col/BNL/Roc/Ill.	Vector-axial vector interference in neutral currents.

*Experiment still in progress as of June 30, 1976.

Experimental Area Development

Along with the day to day activities necessary to maintain an ongoing experimental program, considerable planning and design effort goes into development of new secondary beams for future experiments and development of new equipment and techniques for improving the existing program. In the North Area, a new "narrow band" neutrino beam was built and tested successfully. This beam utilized a set of two focusing elements (horns) with a special geometry of beam stops and collimators to produce a neutrino beam of well defined ($\pm 5\%$) momentum. Knowledge of the incident neutrino momentum will provide an additional physics constraint for new and improved types of neutrino experiments in the North Area.

In order to extend the physics capabilities of the Multi-Particle Spectrometer (MPS) up to the full energy of the AGS, a new High Energy Unseparated Beam (HEUB), utilizing four superconducting dipoles of the ISABELLE design, is being built. By moving some of the superconducting dipoles, the high energy particles can be switched into another branch of the beam to allow other experiments to run. Not only will this beam provide a good quality source of high energy particles, but it will provide additional operating experience with superconducting magnet systems. The electrostatically separated beam which also feeds the MPS will be upgraded by the installation of septum magnets to increase the particle fluxes and improve the beam optics.

Other secondary beam improvements include the modification of an existing muon beam into a very high intensity pion beam, and the installation of a second low energy separated beam. Since the very large fluxes of low energy kaons and antiprotons are almost unique at the AGS, it was felt that these facilities should be expanded so that more experiments could be accommodated.

Since ever-increasing numbers of protons are accelerated by the AGS to meet the demands of the experimental programs, there are problems of radiation damage, and personnel exposure to induced radiation when maintaining equipment. In order to minimize these problems, an extensive program of "radiation hardening" has been undertaken. This includes installation of radiation resistant materials in the vicinity of target stations and the development of special connections and supports such that faulty magnets and other equipment can be removed and replaced in the minimum amount of time.

The computer control system for the AGS secondary beam line magnets is nearing completion. The first beam line was brought into operation in July 1974, and since then six other lines have been completed. During the coming year, four additional lines will be computerized, two of which involve superconducting magnets. The software for the PDP-11 computer, called DIBBUK, has been completed and has proven to be quite reliable. For the past 1½ years, DIBBUK has been used to control and monitor the fast extracted beam (FEB) to the North Experimental Area. This has proven to be of prime importance to protect the 8° superconducting magnet from beam-induced quenches.

Following the concepts successfully used in building the 8° superconducting dipole a one meter window-frame type superconducting dipole magnet has been constructed and tested successfully to 60 kG. This magnet was named the "Model T" because of the T-shaped pieces which were inserted into the iron core from a previous magnet to accept the higher profile of the 60 kG coil. This magnet showed excellent field quality, and can be pulsed at rates up to 5 kG/sec with almost negligible heat losses.

PARTICLE DETECTOR DIVISION

Multi-Particle Spectrometer

The Multi-Particle Spectrometer (MPS), Brookhaven's major spectrometer facility, has been used to do a series of experiments in the momentum range made available by the Medium Energy Separated Beam. Its versatility makes it useful for a large class of counter-spark-chamber experiments at the AGS. The unique characteristics of the MPS are (1) a very large aperture magnet that provides a large acceptance solid angle to detect the reaction products; (2) good momentum and angular resolution, obtained by use of low-mass, high-resolution wire spark chambers and a large magnetic field integral; and (3) the high data-handling capacity inherent in the electronic detectors used (Figs. 17 and 18). The availability of enriched K and antiproton beams from the medium-energy separated beam (MESB) provides exceptional possibilities for excellent experiments with this spectrometer. The MPS is a joint project of the Particle Detector Division of the Accelerator

Department and a research group in the Physics Department. There also has been strong backing and participation in the construction of the facility by potential university users.

All of the first four approved experiments have now taken part of their data, and analysis is proceeding. One result, the discovery of a new resonance, has already been published (A. Etkin *et al.*, Physical Review Letters, **36**, 1482, June 21, 1976).

7-Foot Bubble Chamber

The 7-foot Bubble Chamber is the primary particle detector at BNL for neutrino physics. Since the first picture was taken in October, 1973, a total of 750,000 experimental pictures have been taken. Engineering runs and pulses made when no beam was available bring the total number of expansions made to 1.6 million. About half the pictures have been taken with the chamber filled with deuterium and half with hydrogen.

The analysis of these pictures is still underway, and a great deal of interesting physics is expected from them. One picture in particular (Fig. 19) has already created considerable excitement. The event in it may be the first to reveal the new quantum number called charm.

Targets

One of the vital services provided to users by BNL is the construction and operation of liquid hydrogen and liquid deuterium targets. These targets typically contain a few liters of liquid with a remote reservoir for continuous refrigeration. The system must, in almost every case, be built right

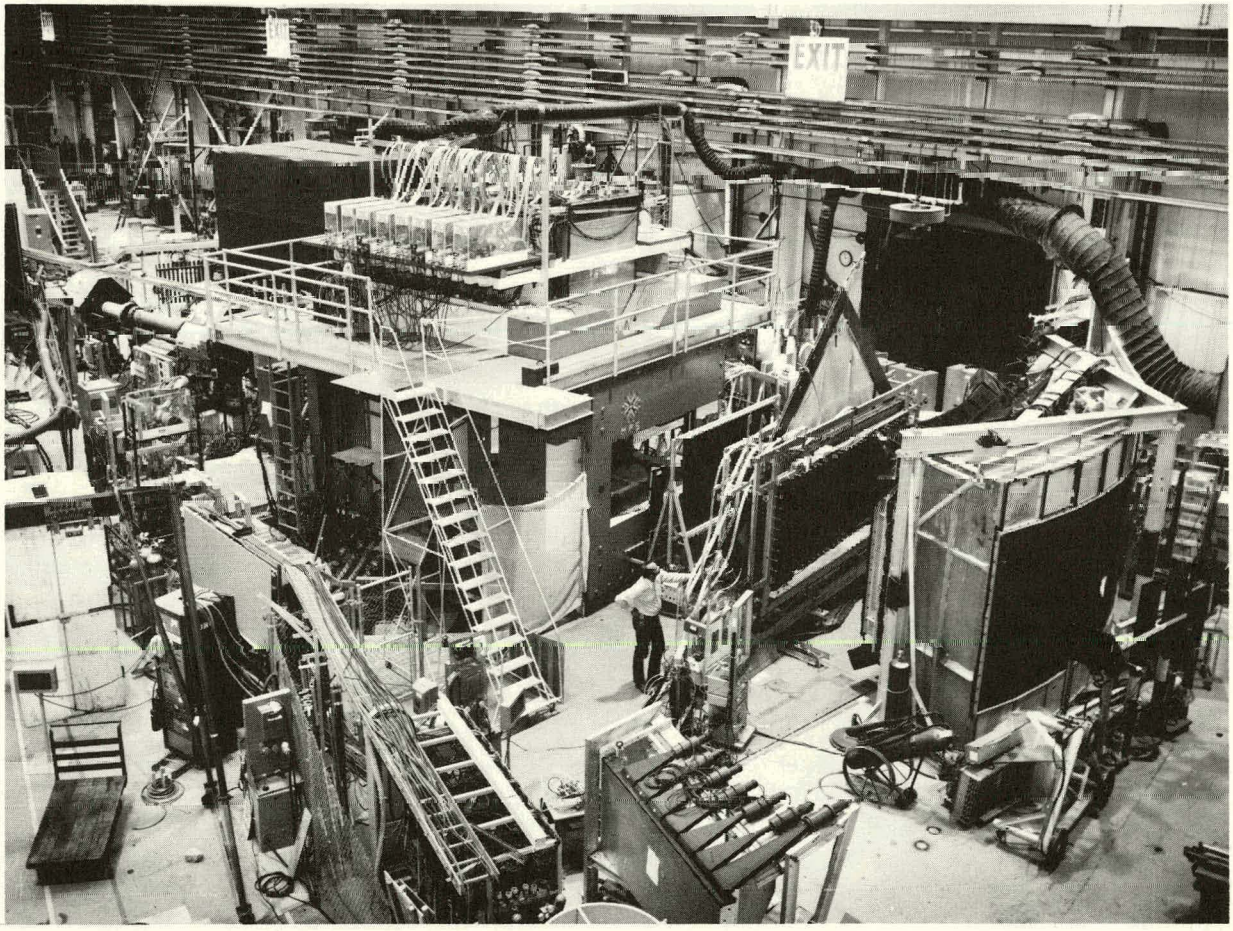


Figure 16. An overall view of the MPS. The beam enters through the two focusing quadrupole magnets and the vacuum pipes in the upper left. It then interacts in a liquid hydrogen target (see Fig. 20) and the interaction products are detected and their momentum measured by cylindrical and planar spark chambers located in the gap of the magnet. Downstream of the magnet scintillator counters, more planar spark chambers and a Cherenkov counter hodoscope identify the particles produced in the interaction.

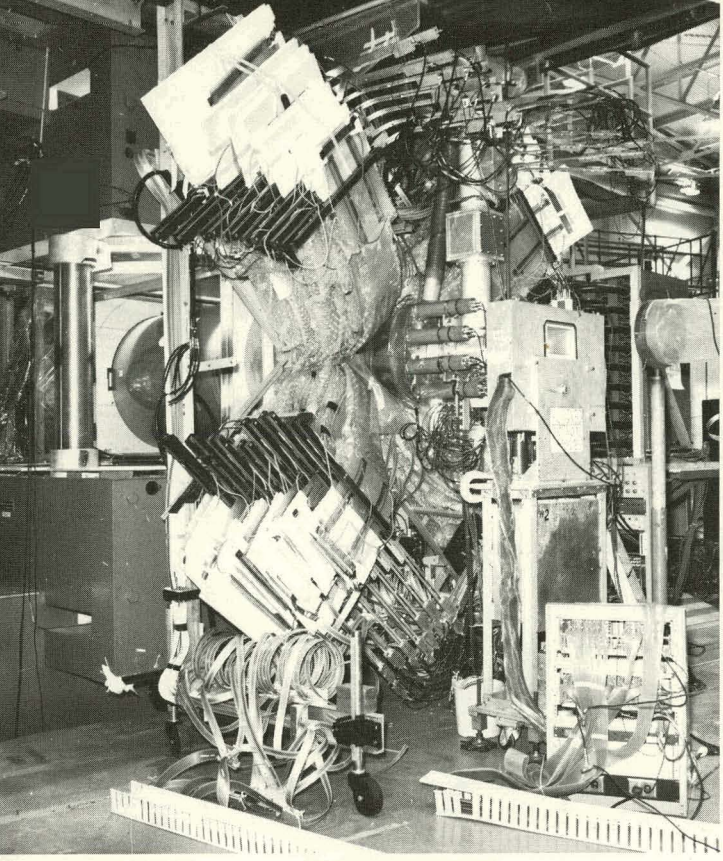
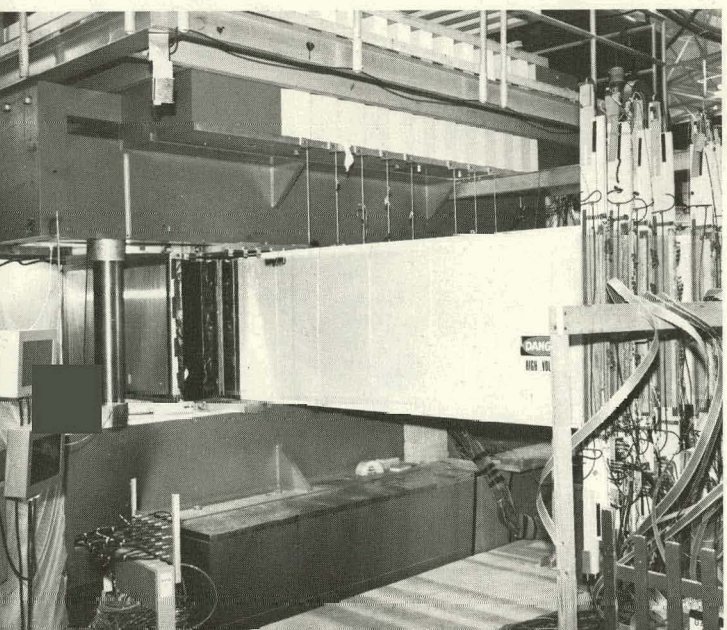


Figure 17. Upstream end view of the huge 630 metric ton magnet of the MPS showing the magnetostrictive readout "tails" of the seven concentric cylindrical spark chambers located in the 1.2-meter high, 1.8-meter wide gap. A liquid hydrogen target is located on the axis of the spark chambers. The beam enters from the right. It passes through the small rectangular window behind which are the proportional wire chambers which determine its position before it enters the target.

Figure 18. Downstream end view of the MPS magnet. The main spark chamber array occupies most of the magnet gap. Just behind the post the last of eight "x" chamber modules (those that give the horizontal position of a particle track) is clearly visible. In the center of the figure, projecting out of the gap to the right, may be seen the readout for the last of seven "y" chamber modules (those that give the vertical position of a particle track).



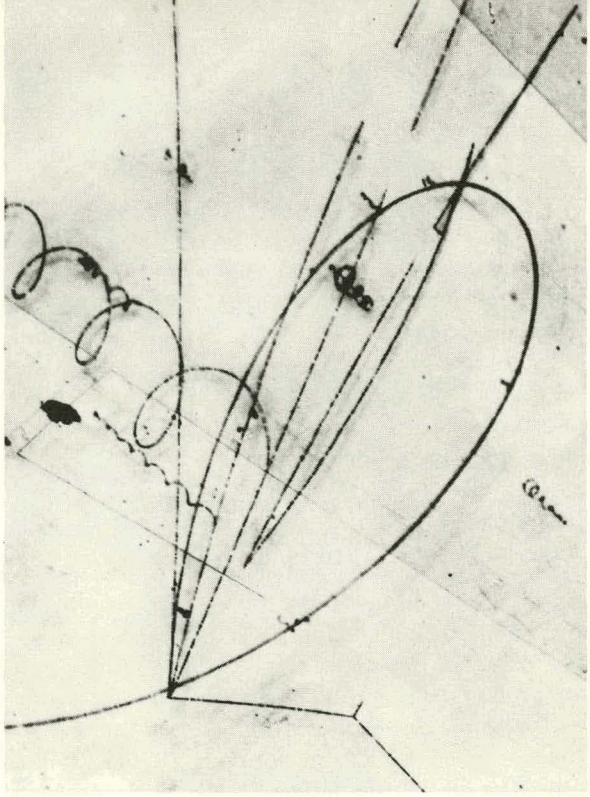
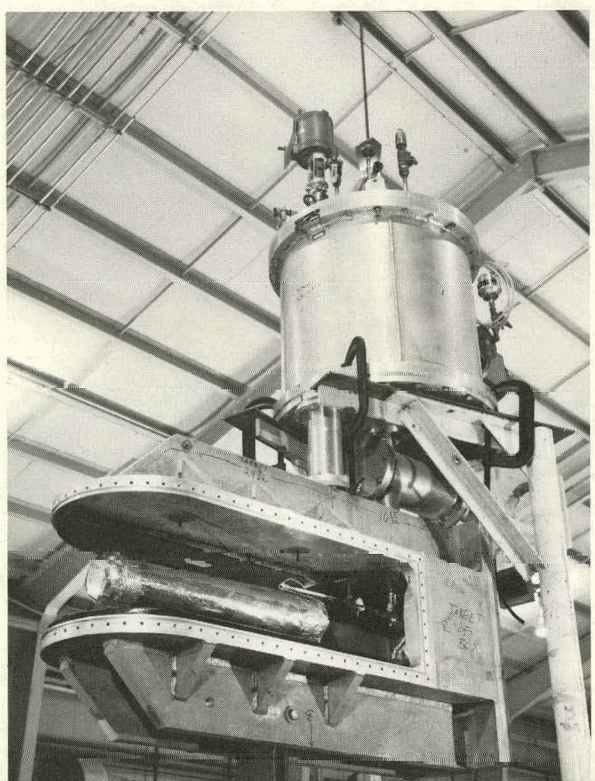


Figure 19. An event in the 7-foot Bubble Chamber interpreted as $\nu + p \rightarrow \mu^- + \Lambda^0 + \pi^+ + \pi^+ + \pi^+ + \pi^-$. The total mass of the recoiling hadrons is 2426 ± 12 MeV. This very likely represents the first observation of "charmed" baryon production. (Cazzoli, Cnops, Connolly, Louttit, Murtagh, Palmer, Samios, Tso and Williams, Phys. Rev. Letters **34**, 1125, 1975).

Figure 20. A typical liquid hydrogen target. The target itself consisting of a Mylar cylinder with metal stiffening rings is shown here wrapped in many layers of aluminized Mylar for infrared radiation shielding. It is inside its vacuum tank from which the Mylar window has been removed. The large cylinder above is the vacuum can within which the cooling reservoir is located.



into the user's experiment. Thus, there is very close cooperation between the users and the engineers and technicians involved in design and construction of these devices. A typical target is shown in Fig. 20. During the last two years there have been 14 targets constructed.

ISABELLE DIVISION

Advanced Accelerator Development

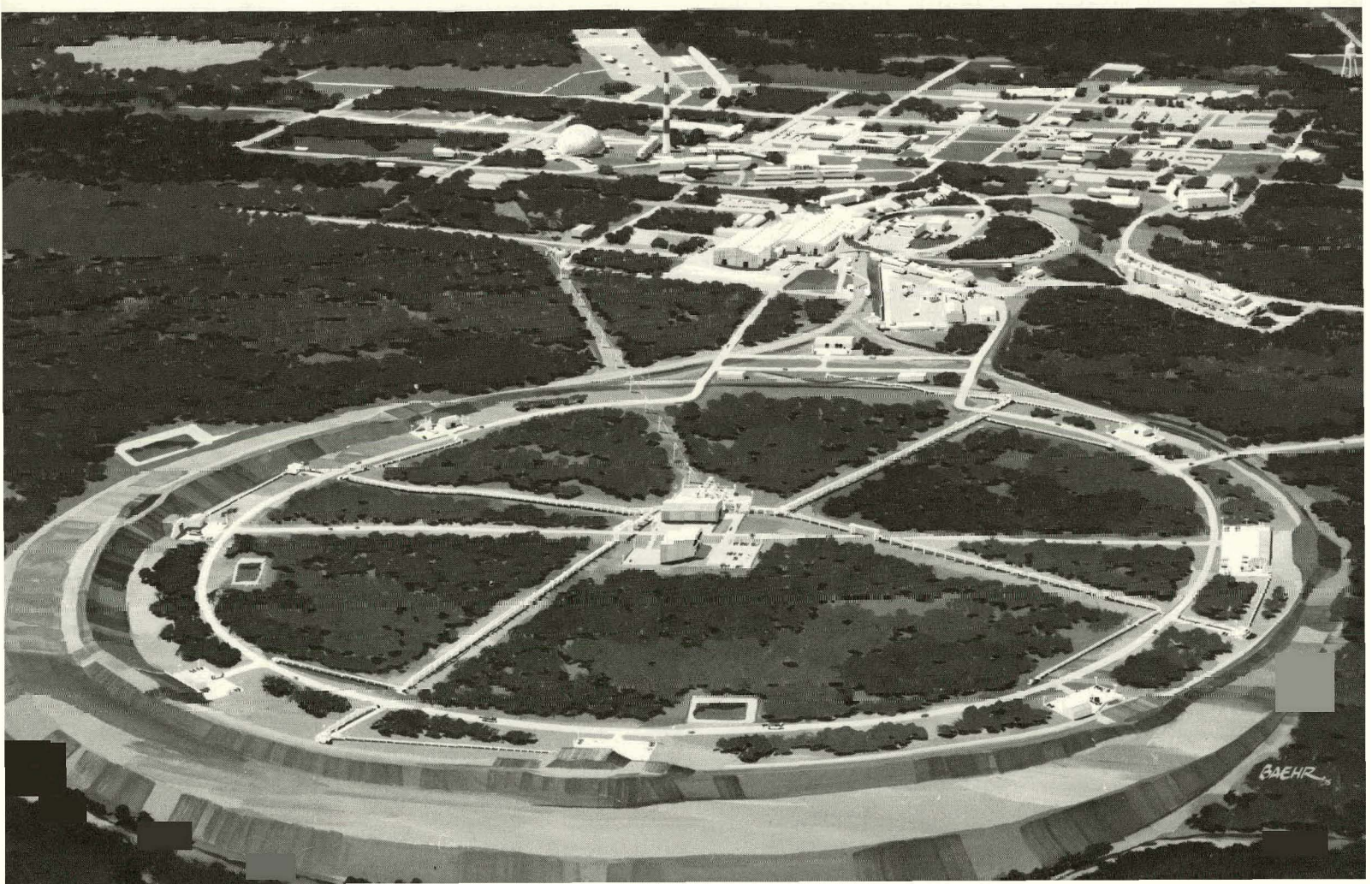
The Accelerator Department carries on a long-range program of substantial improvement of the AGS and the addition of new facilities. In particular, design studies for a proton accelerator of very high energy have been in progress for some years. These studies are coordinated with a continuing research effort in superconductivity to overcome the economic and technical limitations of conventional accelerator designs. During 1970-72, these efforts focused on colliding beam accelerators in the energy range 100 to 300 GeV and culminated in a preliminary design for a 200-GeV colliding beam facility using superconducting magnets, termed the Intersecting Storage Accelerator (ISA), or ISABELLE. Colliding beam machines can generate high center-of-mass energies with relatively modest energies as measured in the laboratory frame. They do not produce secondary beams effectively but they do provide an unparalleled opportunity for studying the reactions of primary particles at the highest possible energies. Two colliding proton beams, each at 200 GeV, would yield a center-of-mass energy of 400 GeV, equivalent to protons of 86,000 GeV striking protons at rest.

200 GeV Intersecting Storage Accelerator

This accelerator would extend the present center-of-mass energy range by almost a factor of ten and, equally significant, provide luminosities* two orders of magnitude higher than those currently available. A number of challenging problems have emerged from recent theoretical and experimental investigations both in this country and abroad. Theories unifying forces underlying

*Luminosity determines the rate at which a particular reaction takes place, the rate being the product of luminosity and the cross section for the reaction in question.

Figure 21. Artist's conception of ISABELLE site looking south.



the weak interaction (responsible for radioactive decay and neutrino interactions) and the classical electromagnetic interaction postulate the existence of a particle known as the intermediate vector boson, with a rest mass well within the ISABELLE energy range. Moreover, the unexpectedly copious production of π mesons with high transverse momentum, seen in recent experiments, may signify a point structure inside the proton. Other crucial questions that the ISABELLE could explore concern the rise in total proton-proton cross section at the highest presently available energies, again at variance with current theories, and the prediction of heavy new particles such as quarks, magnetic monopoles, and massive photons. These problems are at the very forefront of basic science, and their elucidation may deeply affect our understanding of nature.

As a consequence of continuing collaboration between Brookhaven staff members and university colleagues, a revised edition of "A Proposal for Construction of a Proton-Proton Storage Accelerator" was submitted to ERDA in July 1975 in support of a request for construction funds. This revised proposal was used as a starting point for the program of the ISABELLE Summer Study which was held at Brookhaven July 14-25, 1975. While no fundamental changes to the basic design emerged from the many presentations and discussions, a number of areas were delineated where additional research, development, and modeling were appropriate to improve the technical specifications and cost estimates. Typical experimental set-ups were examined in considerable detail and their impact on machine characteristics and experimental facilities was noted.

The ISABELLE design is based on separate superconducting bending and focusing magnets distributed around two intersecting rings located side-by-side in a common tunnel (Fig. 22). The circumference of each ring is 2960 m or 3⅔ times the circumference of the AGS. The configuration is essentially a circle broken by eight symmetrically placed straight insertions in which the beams, travelling

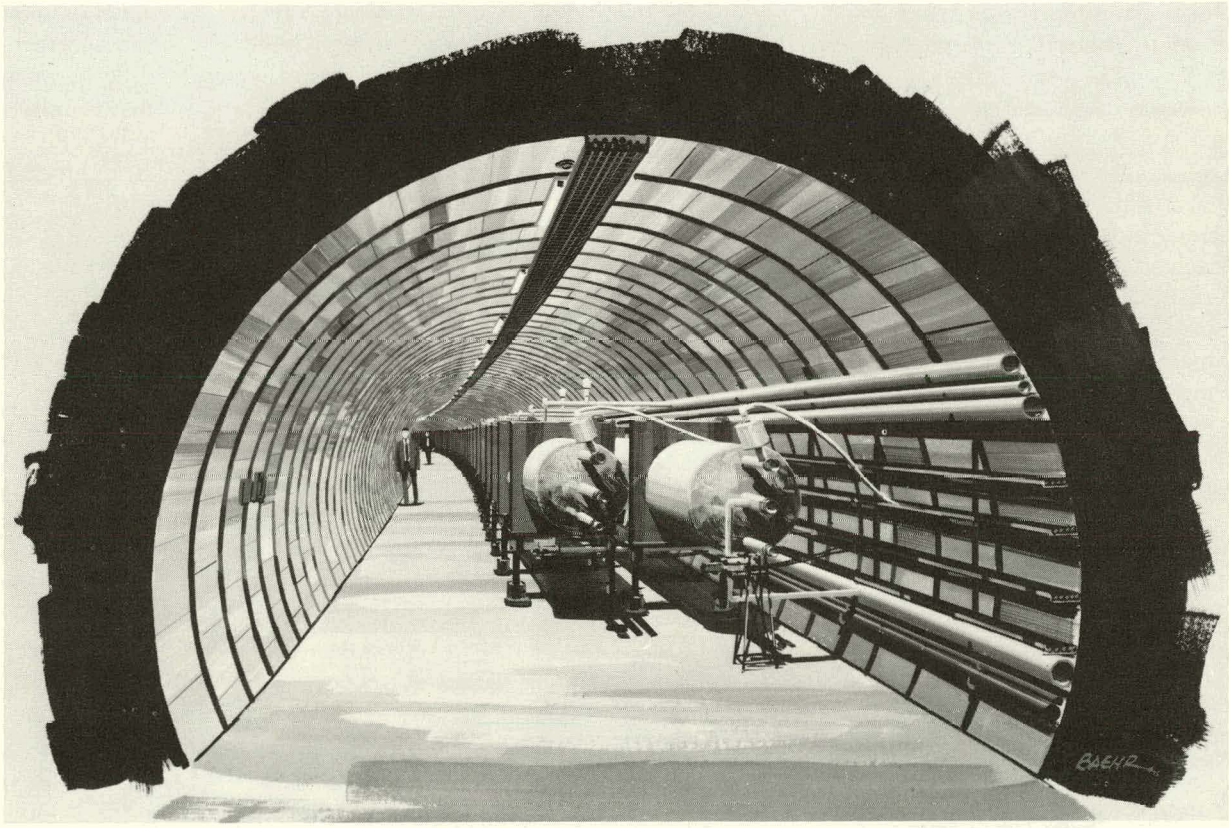


Figure 22. Drawing of typical cross-section of ISABELLE tunnel.

Table IV

Abridged Table of ISABELLE Parameters

Energy	
Maximum energy	200 + 200 GeV
Equivalent accelerator	86,000 GeV
Magnet System	
Circumference ($3\frac{3}{7} \times C_{AGS}$)	2960 m
Bending field for 200 GeV	39.4 kG
Number of dipoles/ring	264
Number of quadrupoles/ring	216
Vacuum chamber diameter	8 cm
Injection	
AGS energy	29.4 GeV
ISA current/ring	10 A
Number of protons/ring	6.2×10^{14}
Acceleration	
Duration	3 min
Energy gain/turn	12.5 keV
Peak rf voltage	40 kV
Experimental Halls	
Number	8

in straight lines, are made to cross in their common median plane.

In the two rings, protons from the AGS are accelerated to a maximum energy of 200 GeV. The method of transferring protons from the AGS to ISABELLE is the same as that used at the CERN ISR; successive pulses of 29.4-GeV protons will be captured, decelerated, and debunched in each ring. This cycle is repeated about 120 times for each ring until a circulating current of 10 amperes is attained. The stacked beams are then rebunched and slowly accelerated to full energy over a 3-min interval. The peak rf accelerating voltage is 40 kV and the energy gain per revolution is 12.5 keV.

The long acceleration cycle and "flat top" associated with this machine make it attractive for superconducting magnet applications. During the past few years superconducting magnet technology has advanced to the point where the performance of magnets can be predicted with considerable confidence. The Department's extensive superconducting magnet development program has culminated in magnets exhibiting excellent stability and having a configuration that meets the severe ISABELLE requirements on field precision, reproducibility, and reliability. Experience gained with superconducting beam transport magnets has shown that radiation damage to magnet components is not as serious as had been thought.

The overall design of the machine permits several options that would enhance the versatility of the ISABELLE facility. Acceleration of electrons in a separate ring inside or outside the ISABELLE tunnel, or possibly one of the two main rings, would permit electron-proton experiments. The addition of a modest bypass to one ring would allow proton-antiproton experiments to be carried out. Moreover, acceleration of deuterons in one or both rings would be relatively straight-forward; this suggests the possibility of neutron-proton and neutron-neutron scattering.

Table IV gives some of the important parameters of ISABELLE.

ISABELLE PROTOTYPE MAGNETS

The superconducting accelerator magnet development program, for which the main initial impetus was provided by the availability of intrinsically stable low-loss superconductors in 1968, has proceeded in several overlapping stages. This led to the construction of a series of ISABELLE proto type magnets beginning in 1973.

A major step toward the full-size prototype was a series of small, 35-cm-long, pulsed model dipoles, designed to produce 40 kG over a 5-cm aperture. Many ideas were investigated, leading to very successful small magnets. These in turn were followed by a succession of 1 m long dipoles with an 8 cm bore and a central field of 40 kG. These 1 meter dipoles fixed the essential features for the prototype magnets.

In May, 1975 fabrication of the first full size ISABELLE model (ISA 4.25 MK I) began. This cos θ type magnet was 4.25 m long with an inner diameter of 12 cm. The superconductor wire was composed of about 500 filaments of a Cu-Ni jacketed NbTi and Cu composite. After a few quenches a field of 36 kG was achieved.

A second full-scale model (ISA 4.25 MK II) was fabricated, incorporating modifications indicated by the tests on MK I. The first quench of the model took place at 40.2 kG. After a few quenches the field reached 45 kG, at 4.6 K.

A full-size prototype of the ISABELLE quadrupole was tested recently. On the first energizing this magnet achieved a gradient equal to the design value of 5.15 kG/cm. After a few quenches, a gradient of 6.55 kG/cm was achieved at 4200 A. The magnet is 1.5 meters long with an inner diameter of 12 cm. The method of construction is identical to that used for the dipole magnets.

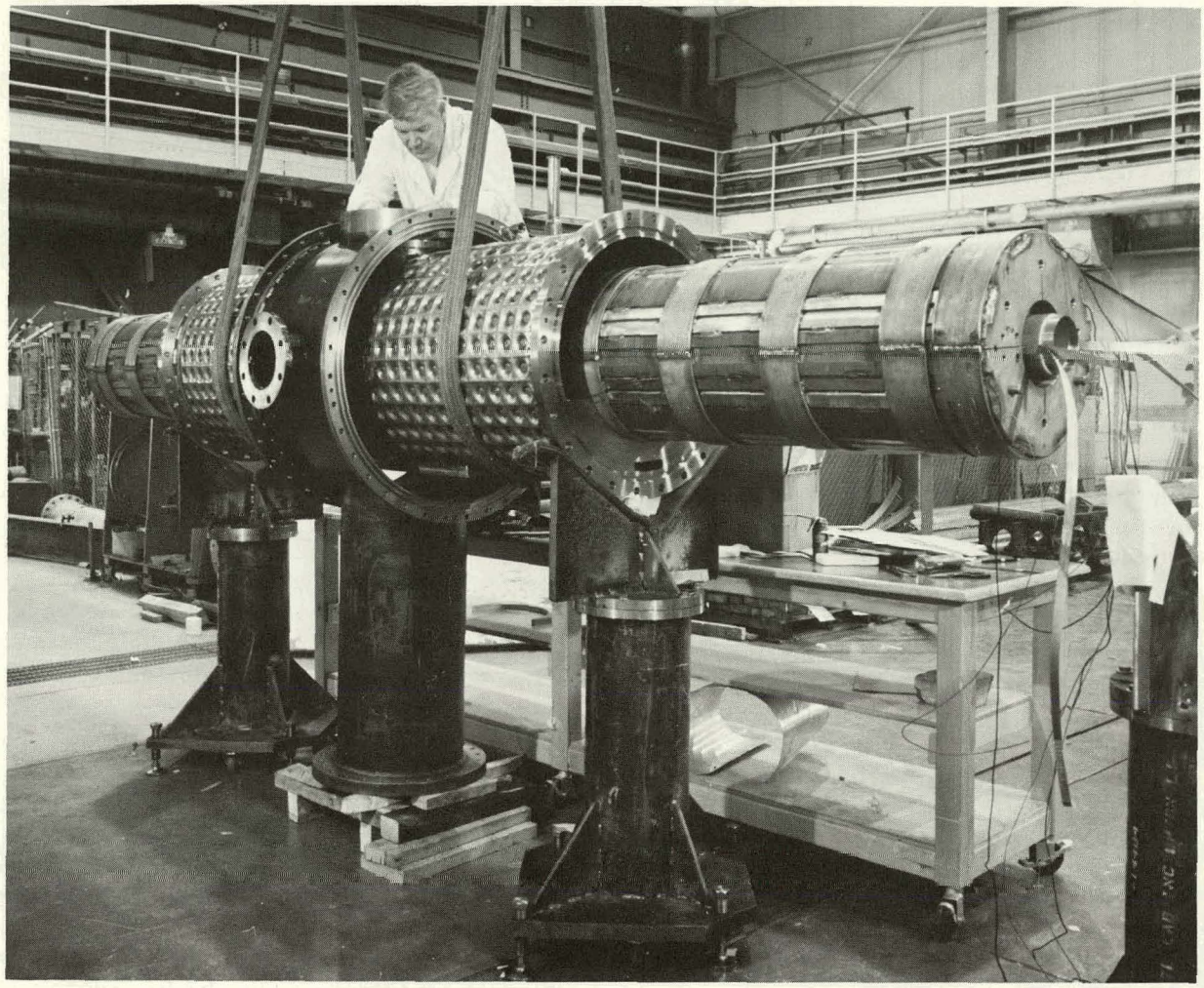


Figure 23. Partial assembly of ISABELLE dipole magnet prototype (split core).

Throughout the development of these magnets a basic concept in the design of ISABELLE dipole and quadrupole magnets is that the iron shield provides support for the coil against the magnetic forces acting on it. This support must prevent any motion of the coil that would result in the coil quenching.

To date, the procedure has been to use an iron shield split horizontally on the median plane, cool the coil to 70 K, and then clamp, and subsequently weld, the shield around the coil. When the coil warms to room temperature, it expands so a compressive preload is applied to the coil. This technique has been reasonably satisfactory. However, significant design improvement with a resulting cost reduction was realized by using an unsplit iron shield and inserting the coil axially into the hole in the shield. Clearance for this assembly procedure was obtained by cooling the coil with liquid nitrogen to 70 K.

To begin to study the problems of many superconducting magnets in a system, a short segment (a half cell) of the ISABELLE ring is under construction. This consists of two dipole magnets and one quadrupole magnet with their cooling systems, power supplies, vacuum system, and computer control. These magnets will incorporate the unsplit core construction and will be cooled by forced circulation cooling.

CRYOGENIC SYSTEMS FOR ISABELLE

The most significant development in cryogenic systems associated with the superconducting magnets is the introduction of forced circulation cooling (FCC) in place of pool boiling. Cooling in the

pool boiling system is accomplished by immersing the magnet in liquid helium. FCC uses helium gas, under pressure, at temperatures slightly lower than for pool boiling. The apparent advantages of FCC over pool boiling are:

1. Heat load reduction through the elimination of many transfer lines.
2. Simplification of refrigeration controls is achieved because the cooling flow is in series through a large number of magnets, thus eliminating the many level controls required by the pool boiling technique.
3. Cost reduction as a consequence of items 1 and 2.

System studies of FCC have been undertaken. There are two cycles which appear to hold the most promise. The first uses an ejector operating between 0.42 atm (3.4 K) and 1.2 atm (4.4 K), the compressor return pressure. The second uses a cold (2.7 K inlet temperature) compressor driven by a turbo-expander. Both systems permit the production of temperatures lower than 4.2 K without undue sacrifice of overall refrigerator efficiency. The refrigeration will be delivered to the magnets by a stream of supercritical helium at a pressure of 15 atm.

The forced circulation cooling mode was demonstrated with a 1-m magnet, whose performance was satisfactory in the pool boiling mode. In the forced circulation cooling (FCC) mode, the magnet reached a field of over 40 kG in the preliminary test.

Ultrahigh Vacuum Systems for Storage Accelerators

To achieve and maintain the required circulating current in storage rings, a vacuum system is required which operates in the 10^{-10} Torr range (3×10^6 molecules/cm^3) in the curved quadrants of the rings and at 10^{-11} Torr in the experimental regions.

The most serious current limitation comes from the beam-induced pressure rise caused by ionized gas molecules being driven electrostatically into the vacuum chamber walls. These liberate adsorbed molecules in a process that can eventually lead to avalanche-like beam destruction. The high desorption coefficients expected from a vacuum chamber operating at liquid helium temperature have indicated the desirability of a room-temperature chamber. This type of vacuum system requires very clean, baked surfaces, and high gas conductance and pumping speeds. The present Isabelle vacuum system design calls for an all-welded aluminum or stainless steel chamber with superinsulation and with pumping provided by a combination of Ti-sublimation and ion-sputter pumps. It is, however, based on several assumptions and extrapolations whose justifications are being scrutinized in experiments intended to yield information on cryosorption, the use of aluminum in high vacuum systems, gas desorption rates, and the insulating properties of various cryogenic superinsulations.

HEUB Magnets

As part of the experimental physics program at the AGS a high energy unseparated beam (HEUB) was designed to provide secondary particles having momenta up to 30 GeV/c to the Multi-Particle Spectrometer. The design of this beam includes the application of four superconducting dipoles to provide a total bend of 20° to the detector.

The four magnets constructed utilize the cosine θ design. Each unit is 2.5 m in length with a room temperature aperture of 20 cm. Total energy per magnet at the design field of 40 kG is 800 kJ. The refrigerator for the HEUB magnets was installed and operated at ratings substantially over the design expectations.

BASIC ENERGY SCIENCE

PHYSICS DEPARTMENT

INTRODUCTION

The Physics Department carries out fundamental research in elementary particle (or high energy), nuclear, and solid state 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 this work in a separate section.

Low or medium energy nuclear physics is in many ways complementary to high energy physics; no formulation of the nuclear forces would be acceptable unless it can also account satisfactorily for the properties and behavior of nuclei throughout the periodic table. Also the properties of nuclei are of vital importance to the design of fission reactors and future fusion reactors for energy production.

Solid state physics is concerned with the properties of matter on an atomic scale. A deeper and broader understanding of materials leads to many possibilities for improving their properties and strengthens and enlarges the technology base necessary for developing energy systems.

Thus the whole Brookhaven basic research program in physics is relevant to ERDA's mission, particularly to its longer-term aspects.

LOW ENERGY NUCLEAR PHYSICS

Research With the Tandem Van de Graaff

The period 1974-1976 was for the Tandem Van de Graaff Facility, which was dedicated in 1970, a period of high technical proficiency and extremely fruitful research activities. Among these activities might be mentioned the search for new nuclear

species, the elucidation of the basic weak interaction by studying nuclear beta decay, and the study of the atomic physics of ions formed in new electronic configurations by means of the Tandem accelerator. One interesting phenomenon, not previously observed, was the mutual Coulomb excitation of two bromine nuclei. When a bromine beam impinged on a bromine target, time coincidences were observed between pairs of the gamma rays emitted following Coulomb excitation of the excited states of Br, thus indicating the target and projectile had both simultaneously been excited by the Coulomb field. Also worthy of mention is a particularly clear example of interference between two types of reaction mechanisms observed in several reactions of the type $^{154}Sm + {}^{12}C \rightarrow {}^{152}Sm + {}^{14}C$. These experiments, which were carried out in a collaboration with Yale University, provided clear evidence for the presence of multi-step processes in the two-nucleon transfer reaction. The study of heavy-ion transfer reactions continues to be the single most extensive research program. After the experimental breakthrough discussed in the last "Highlights," 1974-76 has been a period of consolidation and non-spectacular but significant progress. The collaboration between experimentalists and theorists continues to be a model of cooperation and cross-fertilization in this age of specialization. Some aspects of this program are discussed below under Nuclear Theory.

Indeed, the research program on the Tandem Van de Graaff is an extremely varied one and any selection of projects for detailed discussion is necessarily arbitrary. However, two very productive closely-related programs have come to full fruition in the last two years and have been chosen to exemplify research at the Tandem Van de Graaff Facility.

The development of a wide variety of high quality heavy-ion beams has been given high priority ever since the completion of the BNL Tandem Van de Graaff Facility. The success of these efforts has led to an ever-increasing utilization of high-energy heavy-ion beams as probes of nuclear matter. When two heavy nuclei, such as ^{14}N (projectile) and ^{27}Al (target) or ^{18}O and ^{142}Nd, collide at the energies available from the Tandem Van de Graaff, by far the most likely reaction is the fusion of the two ions into a compound nucleus followed by the "evaporation" of the compound nucleus by emission of neutrons, protons, α-particles, and finally gamma rays. The formation process is quite well described in a simple semi-classical way. The fusion cross section is a large fraction of the geometrical one, πR^2, and the angular momentum of the compound system is close to $\mathbf{L} = \mathbf{R} \times \mathbf{p}$, where R is the grazing radius for the two nuclei. As the name implies, the evaporation process is a statistical emission of low-energy particles carrying low values of angular momentum until a state is reached which decays by gamma ray emission instead of particle emission. This process naturally favors the formation of gamma ray emitting states of high angular momentum (spin) and it was the possibility of studying these high-spin states that made the fusion-evaporation reaction an exciting new tool when it was developed several years ago. As stressed by Bohr and Mottelson in their 1976 Nobel Laureate addresses, it will be a still more exciting tool for the future when we have the technical ability to exploit it fully.

In the rare earth region, the fusion-evaporation process is particularly simple. First, the Coulomb barrier of the compound system is high enough to practically preclude the evaporation of charged particles; hence only neutrons are "evaporated" until the gamma ray emitting states are reached. Second, the gamma ray emitting high-spin states are members of well-formed rotational bands which can be described by only a few parameters. The bulk of the large angular momentum input is removed from the nuclear system by gamma-ray emission in a cascade which ultimately proceeds through the ground-state rotational band. It is through studies of such gamma-ray cascades that one obtains information about the changing behavior of nuclear matter at high spin. In the ^{156}Er nucleus it has recently been found that not one but three distinct paths of de-excitation from the high spin to the low spin states of the ground-state rotational band are followed. Discrete states with spins as high as $24\hbar$ (the highest spin so far observed in reactions of this type) have been identified. The discrete gamma-ray transitions observed as this system de-excites through these three "bands" following the ^{142}Nd (^{16}O,4n)^{156}Er reaction at 95 MeV are shown on the decay scheme (see Fig. 1). The behavior of the moment of inertia for these three bands is shown in Fig. 2 as a function of the square of the rotational frequency. The label a) refers to the mid-band, the ground-state rotational band at low angular momentum, b) to the odd parity left-hand side band, and c) to the odd spin, even parity right-hand side band.

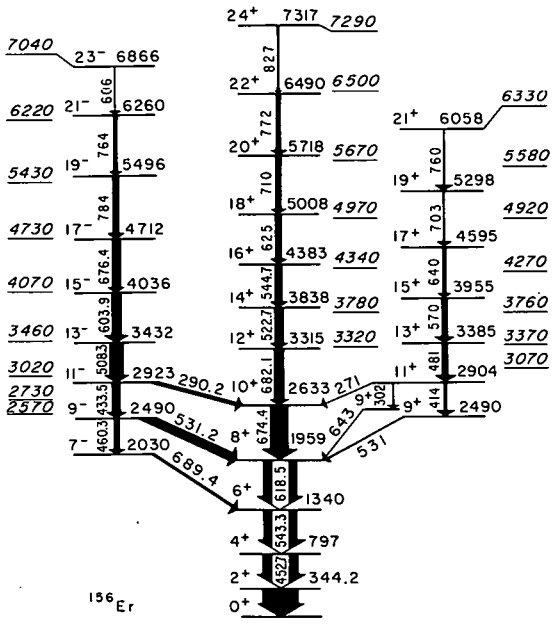


Figure 1. Transitions observed in ^{156}Er following the ^{142}Nd(^{18}O,4n) reaction at 95 MeV. The energy levels predicted by the rotational model are drawn as thin lines adjacent to the experimentally observed levels of corresponding spin and parity and are labeled with italic numerals. The widths of the arrows are proportional to the observed gamma-ray intensities.

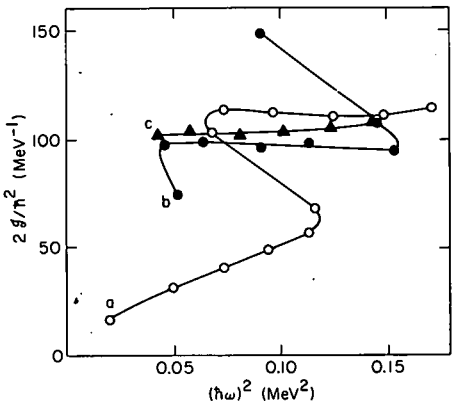


Figure .2 Plots of moment of inertia vs the square of the rotational frequency generated for the a) ground state band, b) odd parity side band, and c) even parity side band in ^{156}Er. The "backbending" in the ground state band is obvious.

These results illustrate that the angular momentum put in is so large that major changes in nuclear structure and stability take place as the nuclear matter system is forced to adjust to the strong centrifugal stresses of rapid rotation. It is believed that the dramatic increase in the moment of inertia shown in Fig. 2 (and often called "backbending") is due, at least in part, to the breaking of the strong correlations between pairs of neutrons or protons. This is analogous to the breakdown of superconductivity in metals by magnetic fields. Theoretical descriptions of the anomalous moment of inertia behavior ascribe the effect to either this change in the matter from a super-fluid to a normal state, or, alternatively, describe it in terms of effects of the Coriolis force upon specific nucleon pairs in specific, single-particle levels.

It is possible to interpret the states of the left-hand side band and those of the ground-state band continuation (the mid-band) satisfactorily in terms of a Coriolis-decoupled, rotation aligned description, which is the second of the theoretical descriptions mentioned earlier. The states of the unique odd spin, even parity side band (so far, no other band of this type has been observed) are not satisfactorily accounted for with respect to energy and other properties by the same microscopic model which works well for the other two bands. A new, as yet unidentified, degree of freedom in the nuclear system may be needed to account for this band, or the theoretical descriptions are still inadequate.

The main areas of research in fusion-evaporation reactions at BNL have been in the rare earth nuclei (such as ^{156}Er), the region $A \approx 100$, and the region $47 \leqslant A \leqslant 33$. In the latter region the Coulomb barrier is low enough so that proton and α-particle emission appear on an equal footing with neutron emission. Thus at any one bombarding energy the number of final gamma-ray emitting nuclei produced is considerably more than in the example of $^{18}O + ^{142}Nd$ just discussed. Some 10–15 nuclei are represented among the gamma rays observed following, say, ^{14}N bombardment of ^{27}Al at 60 MeV. Thus, the approach used to unravel the gamma-ray spectra was to study a large number of projectile-target combinations as a function of bombarding energy. Since each outgoing channel (e.g., 2 neutrons, 1 proton, 1 alpha) has its characteristic behavior as a function of bombarding energy, it is possible in this way to sort out the origin of the vast majority of the observed gamma rays. This is an ambitious program because it involves the simultaneous study of many nuclei before the fine details on any one are all collected. The program has now nearly reached completion and some general observations can be made summarizing the results very briefly. For orientation,

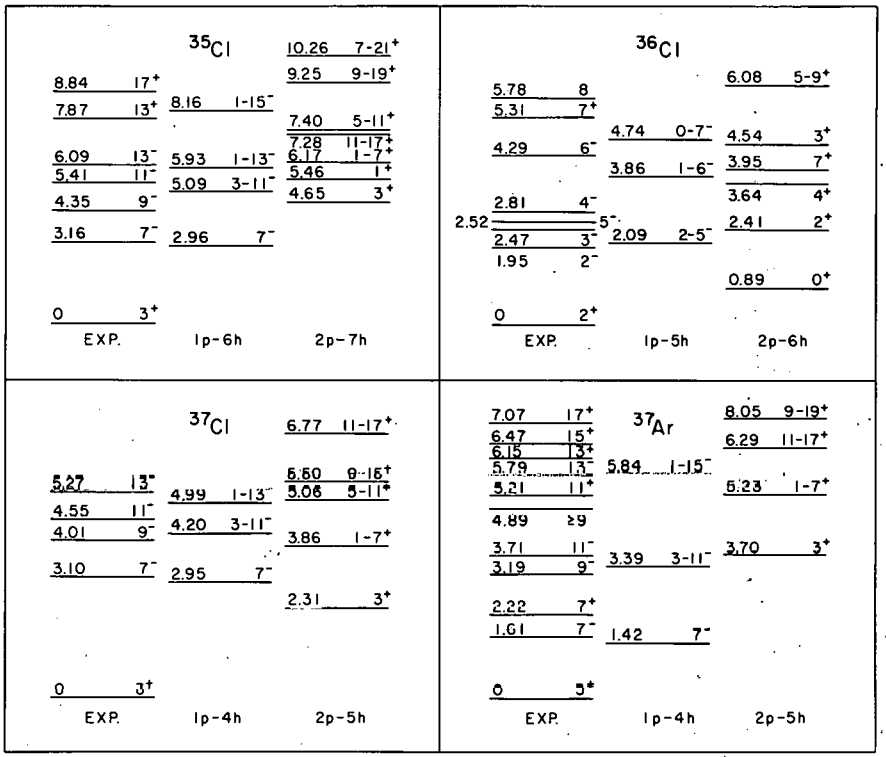


Figure 3. Comparison of the high-spin spectra of ^{35,36,37}Cl and ^{37}Ar to the predictions of weak-coupling calculations. Energies are in MeV. For the odd-A nuclei, 2J is shown instead of J. The predictions give the centroid energies of spin-multiplets.

the spectra of yrast levels* observed for ^{35}Cl, ^{36}Cl, ^{37}Cl, and ^{37}Ar are shown compared to theoretical predictions in Fig. 3. The predictions are those of a simple weak-coupling model which can be viewed as a semi-empirical mass formula and which predicts the binding energies of the levels of a nucleus A in terms of those of the pairs of nuclei $A-n$, $40+n$, where $n=1,2$ in the cases considered. The first point to note is that all the yrast levels observed can be accounted for by the predictions shown. This means that, in shell-model notation, no high-spin states more complicated than two-particle excitations out of the configuration of the ground state into the $1f_{7/2}$ shell beyond ^{40}Ca are observed. This observation is generally true for $33 \leqslant A \leqslant 43$ nuclei, is not expected, and remains to be understood.

Another important generalization is that the electric quadrupole (E2) transitions between the high-spin states for nuclei near the doubly-closed shell at ^{40}Ca are generally single-particle in nature, i.e., there are no collective effects, and except for ^{40}Ca itself, no rotational bands. As we move away from $A=40$, the E2 transitions tend to get stronger and more collective as is expected on general grounds, but still the collectivity is not strong and no rotational structure is observed. A marked exception is ^{40}Ca where a well-developed rotational band built on the 0^+ first-excited state has been observed and followed up to the 6^+ level (and possibly the 8^+ level) by means of the $^{14}N+^{28}Si \rightarrow {}^{40}Ca+n+p$ reaction. Here the E2 rates are very collective and the levels have been assigned to a 4-particle excitation out of the doubly-closed 2s 1d shell into the 1f shell.

*The lowest-lying level of a given spin is termed a yrast level.

Neutron Nuclear Physics

At the Brookhaven High Flux Beam Reactor (HFBR) a strong program continues in the study of the electromagnetic radiation emitted following neutron capture. In addition to the information provided for the design of shielding for slow and fast neutrons, these (n,γ) studies provide important fundamental information on the properties of nuclear energy levels.

A well-established method for determining the angular momentum (spins) of states formed by γ-emission in the (n,γ) reaction follows the empirical observation that the populations of levels with a given spin decrease smoothly with increasing excitation energy and fall on a curve which is separate and distinct from those for other spins, thus providing an aid for spin determinations. These results can be reproduced well by statistical model calculations. Such calculations typically assume that dipole transitions predominate, so that states with spin J de-excite mainly to states with the spins J, J±1. For a γ-ray cascade between the capture state and the final state (typically consisting of three or four transitions), the population intensity is taken to be proportional to the number of independent ways in which a low-lying level of given spin can be reached from the capture state.

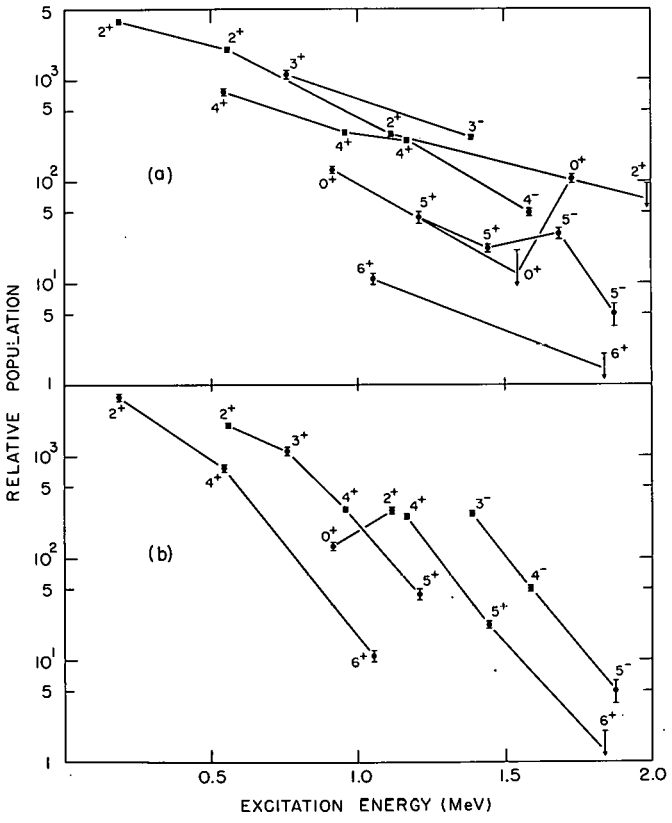


Figure 4. Relative population of states in the $^{189}Os(n,\gamma)$ ^{190}Os reaction at thermal neutron energies. Spin and parity assignments are indicated for each datum point. a) The lines are drawn to connect data points for levels with the same spin. b) The same data as for part a) for all states firmly assigned to rotational bands where two or more members are known. Each line connects the states belonging to a given rotational band.

These observations apply to nuclei near closed shells. At BNL it was conjectured that in rotational nuclei a dependence on nuclear structure might drastically alter the purely statistical process of γ-de-excitation described above. Such was indeed the case. As shown in Fig. 4, the curves obtained by connecting levels of a given rotational band are more distinct and regular than those connecting levels of a given spin. Thus, a new method has been developed for assigning levels to bands in rotational nuclei.

Nuclear Theory

At an early stage, even before the experimental discovery of the anti-proton, Fermi and Yang suggested the nucleon-antinucleon system ($N\bar{N}$ system) might possess bound states, the pi-meson perhaps providing a deeply bound example. The experimental possibility of observing weakly bound or resonant $N\bar{N}$ states has led to a revival of interest in this subject. A non-relativistic potential approximation for the baryons has been used to investigate the existence of bound states or resonances in this matter-antimatter system. The $N\bar{N}$ interaction is obtained by using G-parity invariance together with a realistic one boson exchange potential for the nucleon-nucleon system. The approach seems usable for a restricted class of narrow resonances and weakly bound $N\bar{N}$ states, for which widths are calculated. Should predicted resonances or bound states be observed insight will be gained into both the $N\bar{N}$ and NN systems. In fact an interesting situation arises in observations for low energy antiprotons incident on protons, resonance appearing in the elastic exit channel but not in the charge-exchange neutron-antineutron channel. This paradox is resolved by postulating, and then exhibiting in a model calculation, nearly degenerate isoscalar and isovector resonances which interefere constructively in the $p\bar{p}$, and destructively in the $n\bar{n}$ channels.

The motivation for the study of heavy-ion direct transfer reactions is twofold. Firstly, from the reaction mechanism we learn about such fundamental nuclear quantities as the diffuseness of the nuclear surface and the absorptive nature of nuclear matter for nuclei. Secondly, the reaction is a potentially powerful tool for determining properties of nuclear energy levels such as spins, parities, and wave functions.

Studies at BNL in the last two years have addressed both these general problems. The collabo-

rative experimental and theoretical study of the reaction mechanism for heavy-ion induced direct reactions has produced a generally successful quantitative picture of one-nucleon transfer reactions of the type $^{26}Mg + ^{13}C \rightarrow ^{27}Mg + ^{12}C$ with, however, well defined problems remaining. The same description appears to yield qualitative fits to observed angular distributions for two-nucleon transfer (e.g., $^{154}Sm + ^{12}C \rightarrow ^{152}Sm + ^{14}C$), but is decidedly inadequate in predicting the strength of the latter reactions. It now seems essential to improve upon the single-step distorted wave theory. The observation of interference effects in the $^{154}Sm + ^{12}C \rightarrow ^{152}Sm + ^{14}C$ reaction (referred to in the Tandem Van de Graaff Research section) is one of the pieces of information leading to this conclusion. Simple, multi-step processes, involving for example, the transfer of nucleons together with the excitation of the target and/or projectile, may be present. Efforts in this direction have begun and experiments have been suggested to clarify the situation.

In addition to nucleons, angular momentum is transferred in these heavy-ion transfer reactions. In an attempt to understand under what conditions one can extract the transferred L dependence from the angular distribution, the dependence of the population of the M substates on the final nuclear state of the transferred L has been studied. A simple parameterization of the radial integrals permits approximate calculation of the differential cross sections which depend upon only a few parameters. From this study it is clear that in reasonably well-matched cases, i.e., when the momentum and energy conservations do not have to be made up too much by the transferred matter, and at energies sufficiently high above the barrier, the first peak in the angular distribution uniquely establishes the value of the transferred angular momentum. In a badly matched case the situation is considerably more complicated and no simple shape dependence remains. These simplified considerations increase the usefulness of heavy-ion direct transfer reactions for spectroscopic studies because they allow more judicious choices of experimental conditions.

Tandem Van de Graaff Facility

At the BNL Tandem Van de Graaff Facility a wide variety of light and heavy ions is accelerated to high energies which are very precisely known and easily variable over a wide range. Tightly focused dc and pulsed beams of such ions are used mainly for nuclear physics experiments performed by scientists from BNL and from many other laboratories and universities. Experiments in other fields such as solid state and atomic physics are also important components of the research program.

At present, the Brookhaven Tandem Van de Graaff Facility is the largest and most powerful electrostatic accelerator facility in operation. The last two years were characterized by a continuous upgrading of the capabilities and reliability of the operation. In 1975, 82% of the total time was actually used for experiments; 11% for scheduled maintenance; 5% for development; and only 2% for unscheduled maintenance and repair. At present, the Facility is undergoing a major upgrading in terms of the maximum beam energies and the number of different ion beams available at the maximum energies. The maximum accelerating voltage of the main accelerator is being increased from 11.5 MV (megavolts = million volts) to about 13 MV and a new and very versatile ion source is being installed in the injector machine. The accelerating voltage of this injector will be increased from 7.5 to about 10 MV.

The maximum energies for a given accelerating voltage depend on the charge states that can be reached for a certain ion and are thus functions of the atomic number Z. Therefore, to characterize the performance of these accelerators, curves of energy versus atomic number are used. Such curves are the ones labeled A, B, C, and C′ in Fig. 5. Curve A represents the highest dc beam energies attained elsewhere for experimental use. Curve B shows the performance of the three-stage two-stripper BNL Facility before the present major upgrade program. Curve C is the expected performance after upgrading. These curves correspond to the most probable charge state components, but usually less intense higher energy components can be used. Curve C′ corresponds to higher energy components such that the intensity is 10 particle nanoamperes (6.2×10^{10} particles/sec) for injected beams (I_{in}) of 1 microampere. The points on curve C represent ion species that have actually been obtained at BNL and all of which will become available from the injector after the conclusion of the upgrade program. Most of the missing ion species have simply not been requested in the past and several of them are expected to become available in the future.

Because of the dependence of the Coulomb repulsion between ions on the atomic number of the ions, the Z of the heaviest target which can be studied for a given ion increases rapidly with ion energy. Thus the number of beam-target pairs accessible for study has been greatly increased by the present upgrading and is essentially doubled between curves A and C′.

SOLID STATE PHYSICS

At Brookhaven, solid state physics research emphasizes the study of matter on an atomic scale. The ultimate objective of the program is to relate the properties of materials to their underlying structures and to the effects on these structures of defects, impurities, and the individual and collective motions of the atoms. Special facilities at the Laboratory provide a unique capability for this approach. Foremost among these is the High Flux Beam Reactor, the source of intense beams of low energy neutrons used to probe the structure and dynamics of liquids and solids. In addition, a number of radiation facilities are available to investigate defects in solids. An active program of theory is also maintained to support and guide the experimental program and additional support is provided by materials research groups in other departments of the Laboratory, especially on energy-related projects.

Neutron Scattering

Neutrons are generally considered to be the most versatile probe of condensed matter presently available. Within recent years, neutron research has spanned a wide variety of subjects from lattice dynamics in solids to spin dynamics in magnets and from investigations of the mechanisms underlying phase transformations to studies of the structures of monolayer gas films on surfaces. The following examples were selected from the Brookhaven program to illustrate the range of problems of current interest and to give an indication of the types of information obtained from neutron experiments.

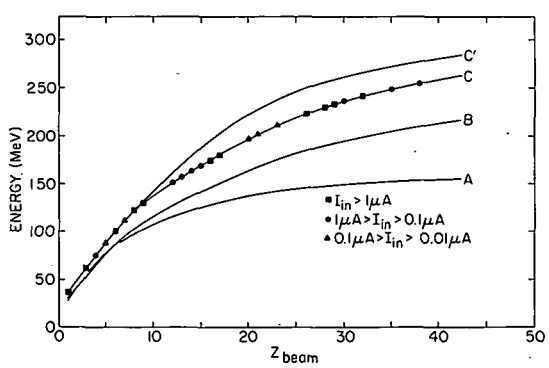


Figure 5. Performance characteristics of the BNL Tandem Van de Graaff. Maximum energy of accelerated ion versus the atomic number (Z_{beam}) of the ion: A) highest dc beam obtained elsewhere; B) the BNL Tandem prior to 1976; C) expected performance after 1976 upgrading; C′) expected energy for 10 particle nanoamperes.

To a considerable extent, our present understanding of metals is based on the so-called "one-electron" picture in which conduction electrons are regarded as interacting with one another only in a certain average (self-consistent) sense. For many metals, a more exact treatment of electron-electron interactions does not lead to fundamentally different results. But in certain cases, the interactions which are neglected in a one-electron model play an important role and cause the normal metallic ground state to become unstable against the formation of a new, more complicated configuration. Superconductivity is the most familiar example of such an effect (called a Fermi surface instability): it produces a ground state in which conduction electrons with opposite spin orientations are paired.

Another kind of Fermi surface instability, discovered within the past few years, leads to a ground state in which there is a spatially periodic variation in the conduction electron density. These periodic charge density variations are known as charge density waves (CDW's) and were first observed in layered compounds such as $TaSe_2$. Their formation is strongly favored by distortions away from an isotropic Fermi surface. Thus CDW's are found to occur in some of the newly discovered quasi-one-dimensional metals such as potassium chloroplatinate (KCP) and tetrathiafulvalene-tetracyanoquinodimethane (TFF-TCNQ).

Neutrons do not interact directly with CDW's, but such charge density waves can be detected nonetheless, because they distort the crystal lattice when they appear. Elastic neutron diffraction studies show that CDW's form spontaneously below a well-defined threshold temperature and that the amplitude of the wave increases smoothly to a saturation value as the temperature is lowered. The wavelength may also change with temperature, starting with an incommensurate value and gradually "locking-in" at a multiple of a lattice dimension.

While elastic neutron diffraction tells us how CDW's evolve after they appear, it does not tell us anything about their origin. Inelastic studies reveal, however, that the frequencies of lattice vibrations whose momenta exactly match certain dimensions of the Fermi surface are drastically reduced as the temperature decreases. This is illustrated in Fig. 6 which shows data for KCP. It is believed that this "softening" of the lattice vibration frequency presages the formation of CDW's.

Other neutron scattering studies have provided insight into the interaction of CDW's with impurities and with each other. Ultimately, it is hoped that these investigations will be of practical value because superconductivity and CDW formation are competing processes – the one occurring first tends to suppress the other. Since both are favored by strong interactions between electrons and lattice vibrations, it may be that improved high temperature superconductivity would result if ways to supress CDW instabilities could be found.

Superionic conductors are materials which are basically insulators but become conducting because they contain ions with high mobilities. They are of potential interest for storage batteries of light weight and high capacity. Ionic conductors contain equivalent sites within their crystal lattices in which ions can localize. Charge motion occurs because the ions move with relative ease from one such site to another. The nature of these sites and the details of the conduction mechanism can be studied to advantage with neutrons.

Fluorides such as BaF_2 and PbF_2 show ionic conductivity. In these materials, the mobility of negatively charged fluorine ions is known to increase dramatically with increasing temperature. Elastic neutron diffraction studies show that when heated to 200°C below their melting points, approximately 40% of the fluorine ions in BaF_2 and PbF_2 have moved from their equilibrium positions in the face centered cubic lattice to interstitial sites, indicating their involvement in the conduction process.

Another group of ionic conductors of interest include the beta aluminas, materials composed of blocks of Al_2O_3 separated by planes of conducting ions such as Na^+, Ag^+, Rb^+, and others. Within the host lattice there are more available sites for these ions than there are ions and conduction is by means of diffusive jumps from one equivalent site to another. Between jumps the ions remain localized. The oscillatory motions of the ions localized

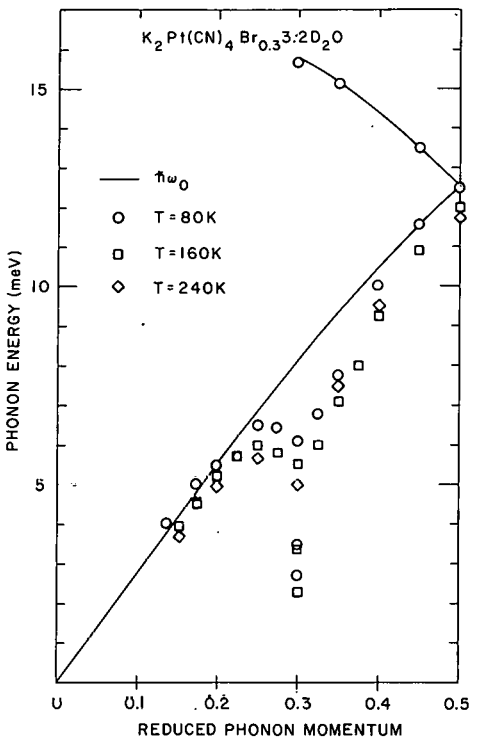


Figure 6. Lattice vibration frequencies in KCP as a function of reduced momentum. Note the dramatic drop in frequency at 0.3 with increasing temperature.

at lattice sites can be studied with inelastic neutron scattering. Oscillation frequencies are found to decrease with increasing ionic size. For Na^+ ions, a sharp localized oscillator frequency is observed; when, however, Ag^+ is substituted for Na^+, the neutron data indicate that the localized oscillator frequency decreases markedly and is broad and ill-defined.

The properties of solid surfaces are the determining factor in many processes of practical importance such as friction, heat transfer, and catalysis. Often, it is not the surface itself but the gas layer (or layers) adsorbed on it which plays the crucial role.

One of the best materials for surface studies is graphite which is available in a number of finely divided forms with large specific areas and surfaces of exceptional uniformity and homogeneity. On graphite, certain gases are known to form two-dimensional (2D) structures and these are believed to undergo changes of state analogous to the solid-liquid-vapor transitions of the more familiar 3D matter. Neutron scattering methods can be applied to advantage to study these monolayer films.

Typical of such systems is argon adsorbed on Grafoil, a basal-plane-oriented graphite. Figure 7 shows the elastic diffraction pattern observed from a monolayer of the separated isotope ^{36}Ar (an intense neutron scatterer) at a temperature of 5 K. There are three peaks evident in the figure. These can be indexed as the (10), (11), and (20) peaks of a triangular lattice with a nearest neighbor distance of 3.88 Å. The structure is incommensurate with the periodicity of the underlying graphite lattice but is almost identical to a single plane of atoms in the face centered cubic lattice of 3D argon. It is evident that interactions between the gas atoms, rather than interactions between the gas atoms and the underlying carbon atoms, are the determining factor in defining the structure of the adsorbed layer.

Films such as this exhibit many of the characteristics of idealized 2D solids. One curious feature of their behavior is their rapid thermal expansion. Between 5 and 60 K, the total linear expansion of the ^{36}Ar monolayer is found to be 9%, the most rapid increase occurring between 40 and 60 K. By contrast, solid argon has a linear expansion of only 2% over the same temperature range. Melting is also dramatically different in the 2D film. As the temperature is increased, the diffraction peaks broaden continuously indicating a gradual decrease in the range of crystalline order with no well-defined melting transition. This is to be compared with melting in 3D solids in which crystalline order is observed to disappear abruptly at the melting temperature.

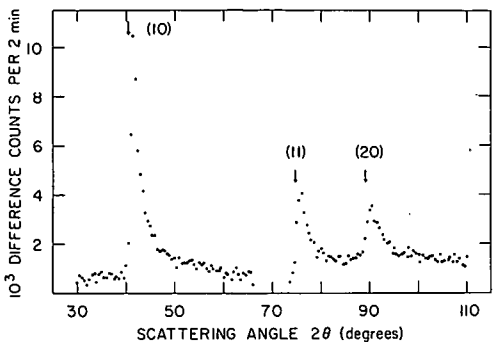


Figure 7. Neutron diffraction from a monolayer film of ^{36}Ar adsorbed on Grafoil.

Defects in Solids

Imperfections in crystals play a major role in determining their macroscopic properties. Two main avenues of investigation of defect formation and structure are emphasized at Brookhaven. One involves the use of energetic particles and ionizing radiation to create defects. The resulting effects on the physical properties of the solid are then studied. The other uses particles and radiation as probes to furnish basic information of interest. Both have as their goal a more complete understanding of the properties of real solids, i.e., solids containing defects. Aside from its basic scientific interest, this program also has important practical applications since 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 highly technological society. The examples to follow indicate two of the methods used to attack these problems and the kinds of information obtained from their application.

Experience to date makes it clear that the intense radiation levels anticipated in controlled thermonuclear reactors will seriously alter the structural properties of the materials used to construct the reactor vessels. Consequently it is important to know in advance as much as can be learned about the defects produced in crystals by irradiation. One of the tools being brought to bear on this problem is Raman scattering, a term used to describe the inelastic scattering of light by matter. In most cases the scattering is produced by interaction of light with vibrations of the crystal lattice and with defects within its structure. In the scattering process the light can either gain or lose energy, the difference reflecting the frequency of vibration of the lattice or the defect. Furthermore, the polarization of the scattered light provides important information about the symmetry of the defect and the nature of its vibration.

The amount of light inelastically scattered from defects is small, often less than 100 photons per second in a typical case. To obtain reliable information with such low intensities a system combining polarization modulation with digital synchronous detection has been developed. In this system the detector has two separate digital counters and the optics and associated electronics are constructed so that photons of a particular polarization are registered in one counter while those of orthogonal polarization are registered in the second counter. By employing digital techniques photon counting can be continued until sufficient data are collected to yield highly accurate values of the intensity and polarization.

Currently, the method is being applied to gamma-irradiated sodium chlorate and to neutron-irradiated aluminum oxide. It is also suited to the investigation of crystals containing impurities. The influence of impurities on the ferroelectric ordering transition in a variety of ferroelectric crystals is now under examination.

Positron annihilation is also used to study defects in solids. When positrons are injected into a metal they quickly lose energy by collision processes and come to thermal equilibrium. The rate of their subsequent annihilation by combining with electrons is proportional to the electron density at the annihilation site. Consequently, positron lifetimes in a metal are a measure of the local electron concentration. In addition, the energy spectrum of the gamma rays resulting from the reaction reflects the momentum distribution of the electrons involved in the annihilation process. Positron annihilation at rest produces a pair of 0.511 MeV gamma rays representing the conversion of the rest mass of both particles to energy. When the electrons are moving, the gamma energy is shifted to slightly larger values because both rest mass energy and kinetic energy are conserved in the reaction. This shift is thus a reflection of the kinetic energies of the electrons at the annihilation site.

When a positron comes near a defect it tends to be trapped at that location. Since the electron density in defects is lower than in other parts of the lattice, positron lifetimes increase and the difference can be used to indicate the defect density. For example, as a solid is heated the number of lattice vacancies increases. Positrons become trapped in these vacancies and changes are observed in the annihilation characteristics which can be directly correlated with the increase in vacancy concentration. The technique can detect a few missing atoms in a million lattice positions. Other types of defects such as voids and dislocations can be successfully investigated with this method.

Theory

Certain organic substances have attracted widespread attention within the scientific community because they are unusually good conductors of electricity in certain directions, and it is thought that at some future time they may be the source of a new class of useful materials. Tetrathiafulvalene-tetracyanoquinodimethane (TTF-TCNQ), the most promising of these, has its constituent molecules arranged in two types of chains. Electrical conductivity in this material is particularly high close to the temperature at which a sudden change takes place in the lattice structure. Comparison of neutron scattering data with theory shows that only one of the two kinds of chains is involved in the initial structural change and it is this chain which is responsible for the high electrical conductivity. It is hoped that further invesigation will lead to a deeper understanding of the mechanisms involved in this behavior and will contribute to the development of other, more useful, compounds.

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CHEMISTRY DEPARTMENT

INTRODUCTION

The definition of chemistry is so broad – "the science that treats of the composition of substances and the transformations they undergo" – that almost any problem in any of the sciences dealing with matter is properly a chemical problem, requiring the skills of the chemist to study it. This is strikingly illustrated by the wide variety of researches in the BNL Chemistry Department, a selection of which is described below. They range from investigations of severely practical interest (e.g., the development of radiopharmaceuticals for use in the diagnosis of disease, and the use of nuclear techniques for the measurement of environmental pollution levels), through studies of chemical and nuclear structure and reactions, to investigations of interest to astrophysics and cosmology (e.g., the measurement of the neutrino flux from the sun). In the last few years increased effort has been devoted to energy-related problems.

THE BROOKHAVEN SOLAR NEUTRINO EXPERIMENT

A series of nuclear reactions in which hydrogen atoms are converted into helium atoms is the source of the sun's energy. Because the tempera-

ture necessary to sustain these reactions is high enough only in the core of the sun, the only direct nuclear reaction products produced in the fusion process that are penetrating enough to escape from the sun and be detectable on earth are neutrinos. All other fusion products are absorbed and converted into heat in the sun's core.

The Brookhaven solar neutrino experiment was designed to observe the solar neutrino radiation and to test the theories that predict details of the fusion reaction chain, the temperature, pressure, and interior structure of the sun. Neutrinos are observed by their interaction with ^{37}Cl to produce ^{37}Ar, which is radioactive. Since neutrinos have an extremely small interaction probability, 379,000 liters of target material (C_2Cl_4) are used to produce the few argon atoms per day which are predicted. Additional details of the experiment are described in the 1970-72 issue of "Brookhaven Highlights."

Measurements extending over a period of eight years have shown that the solar neutrino flux is lower than expected from theoretical models of the sun. Current theoretical models using the standard input data for the solar composition, mass, age, and luminosity, and the accepted laboratory measurements of the nuclear reaction cross sections, predict a neutrino capture rate in ^{37}Cl of 5.8 SNU (SNU = solar neutrino unit = 10^{-36} captures/sec/^{37}Cl atom). Solar neutrinos have not been observed in the Brookhaven experiment, but the measurements have yielded an upper limit, set at 1.8 SNU, to the solar neutrino flux.

The low flux of neutrinos from the sun established by the experiment has stimulated a number of astrophysicists to reinvestigate their fundamental picture of the structure and evolution of the sun. One suggested explanation of the low neutrino emission is that the sun could be depleted in heavy elements in its interior. According to this idea, the sun was initially formed of hydrogen and helium, and the heavy elements were added to its surface subsequently, so much later that they have not been mixed into the interior. Another explanation being actively discussed is that the energy generation processes and the sun's luminosity are periodic, and the low neutrino result is due to the sun now being in a stage of low energy production. If this theory is valid it would also provide an explanation of the periodic glaciation of the earth.

The calculated sensitivity of the Brookhaven solar neutrino detector is dependent upon knowing the neutrino capture cross section of ^{37}Cl as a function of the neutrino energy. The cross section used is deduced theoretically. Although this calculation is considered to be extremely reliable, in view of the unique character and the important implications of the Brookhaven experiment it is generally thought that it should be checked by direct experimental measurement. Such a measurement is being planned in collaboration with Purdue and Northwestern Universities. It will use the neutrinos from μ^+ decay at the Los Alamos meson facility.

It is generally agreed that if the sun is producing energy by nuclear fusion reactions the initial step is the proton-proton reaction

$$H + H \rightarrow D + e^+ + \nu .$$

The neutrinos from this reaction have energies too low to be observed by the present Brookhaven solar neutrino experiment; a neutrino capture reaction with a sufficiently low threshold is required. The most suitable such reaction is the capture of neutrinos by ^{71}Ga to produce ^{71}Ge (half-life 11 days). Development of a radiochemical solar neutrino detector system based upon this reaction is being carried out. This experiment will require at least 18 metric tons of gallium in the form of either gallium metal or $GaCl_3$ in aqueous solution.

Another solar neutrino detector system being studied is based on the capture of neutrinos in ^{7}Li to produce ^{7}Be (half-life 53 days). This reaction is chosen because of its high cross section for the relatively low energy neutrinos from the

$$H + e^- + H \rightarrow D + \nu$$

reaction, a reaction related to the proton-proton reaction above. The ^{7}Li neutrino detector, if experimentally feasible, can resolve the crucial question of whether the basic reaction is occurring in the sun. Studies are being made of methods of extracting a few atoms of ^{7}Be from large quantities of concentrated lithium chloride. A major difficulty to be overcome is the development of a sensitive low-background counting technique for measuring ^{7}Be activity. If the ^{7}Li detector system proves feasible, a large-scale detector employing 109 metric tons of LiCl will be proposed.

NUCLEAR CHEMISTRY

The nuclear chemistry program encompasses two general areas: nuclear reactions and nuclear spectroscopy. The aim of the former is understand-

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Figure 1. The Brookhaven Solar Neutrino Detector tank, located 1478 meters underground, in the Homestake Gold Mine in Lead, South Dakota. The tank contains 379,000 liters of perchloroethylene liquid. The great depth in the mine is required to provide adequate shielding from cosmic rays. Capture of a neutrino from the sun by one of the isotopes of chlorine in a perchloroethylene molecule produces an ^{37}Ar atom, a radioactive isotope with a 35-day half-life. The ^{37}Ar is extracted from the perchloroetylene liquid by purging with helium gas. After purification, the sample obtained consists of a few atoms of ^{37}Ar in about 1 cc of ordinary argon. This sample is transferred to a small gas poportional counter and its ^{37}Ar radioactivity is measured by means of the apparatus shown in Fig. 2.

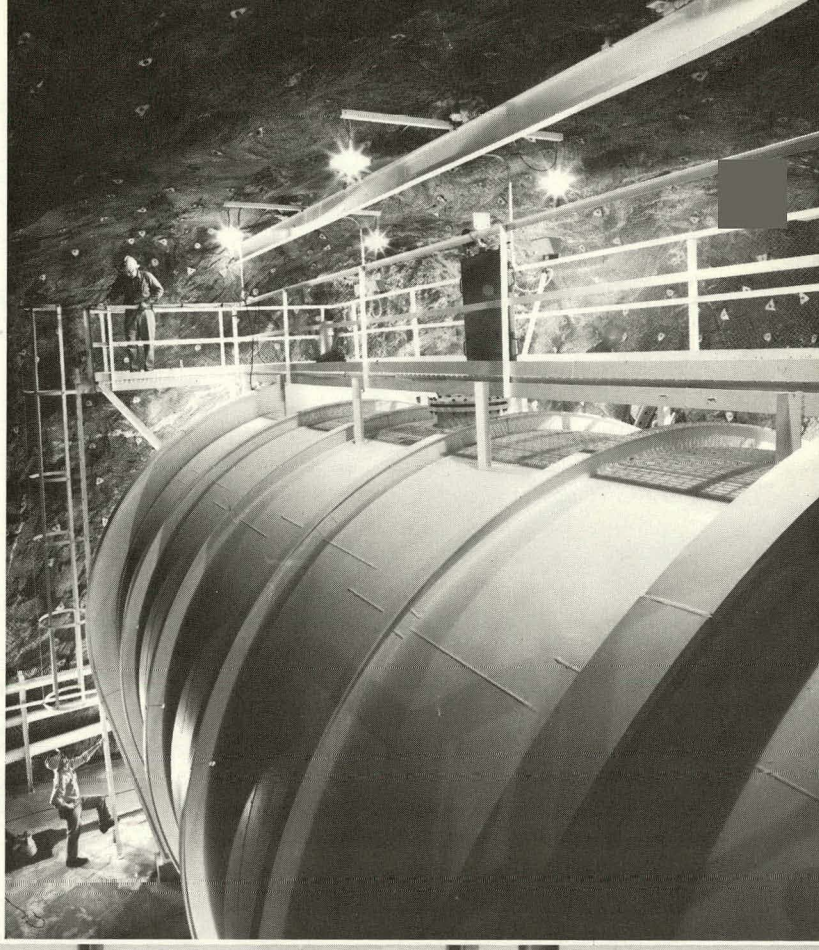


Figure 2. The low-level counting system and shield used to measure ^{37}Ar activity in argon extracted from the 379,000-liter tank. Four samples, each in its own small gas proportional counter, can be counted simultaneously. They are held inside a 30.5 cm diameter sodium iodide crystal that serves as an anti-coincidence guard counter to reject spurious counts due to cosmic rays. The counting assembly is shown being lowered into a well in a large cylindrical mercury-filled shield for the measurement. On the left is the electronic recording system. Argon-37 counting rates as low as one count in 50 days can be observed with this counting system.

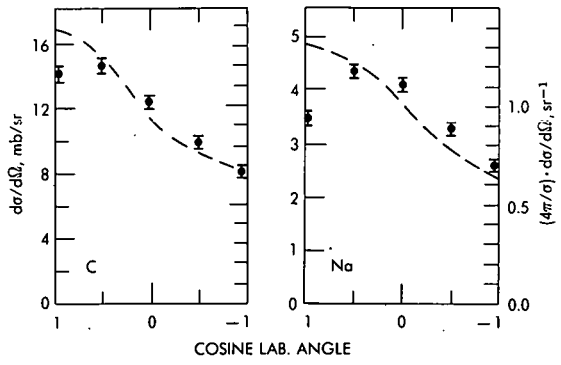


Figure 3. Laboratory angular distributions of carbon and sodium fragments from uranium irradiated by 28-GeV protons at BNL. The dashed curve at left represents carbon from uranium determined at LBL at 5.5 GeV; dashes at right represent ^{24}Na from bismuth determined at BNL at 2.9 GeV.

ing the behavior of complex nuclei when they are bombarded by projectiles of medium to very high kinetic energies. While early studies focused largely on high energy protons as the projectile, recent work has been extended to include the relativistic heavy ions available at the Lawrence Berkeley Laboratory (LBL) Bevalac as well as more exotic particles such as π mesons. Nuclear spectroscopic studies have emphasized searches for and characterization of new isotopes on the neutron-rich side of the line of beta stability.

Nuclear Reactions

The process by which fragments such as ^{24}Na are ejected from heavy nuclei under bombardment by high-energy projectiles is not well understood. One of the more significant recent observations is that the light fragments produced by bombardment of Au and U targets with beams of 28-GeV protons are emitted preferentially sideward. The apparatus used to obtain these results is a scattering chamber located in an external beam at the AGS. Atomic numbers of individual fragments are identified by simultaneous measurement of rate of energy loss and total energy. Angular distributions for C and Na fragments are shown in Fig. 3. These are typical of fragments with atomic numbers between 6 and 20; they show broad peaks centered at $\approx$70° to the beam direction. This was completely unexpected, as previous studies (at BNL and LBL) at lower proton energies showed only forward peaks. The presence of these sideward peaks may be evidence for the generation of nuclear shock waves, a process that has

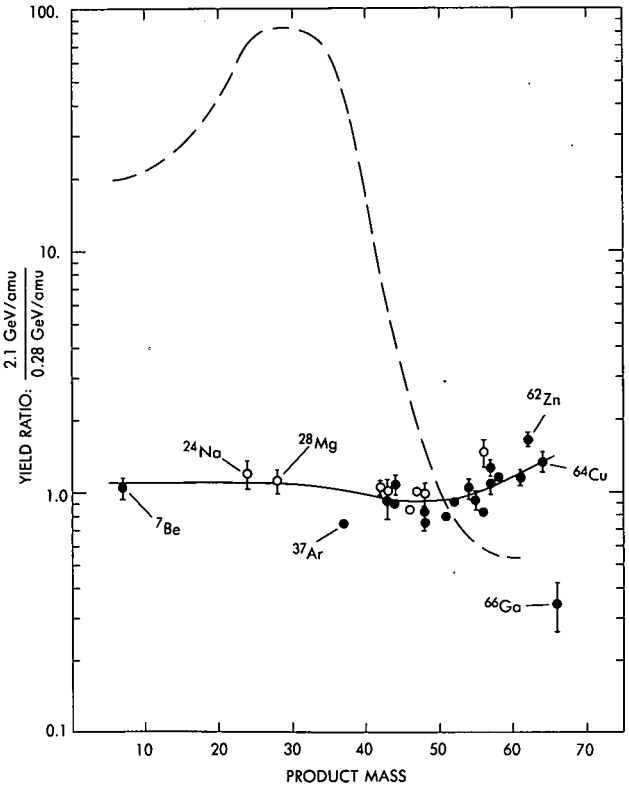


Figure 4. Yield ratio for products from copper bombarded with 2.1-GeV/amu ^{12}C ions and 0.28-GeV/amu ^{14}N ions. The corresponding variation of the yield ratios for bombardment with protons in this energy range is shown by the dashed curve.

been discussed extensively as a possible mechanism for reactions induced by very high energy heavy ions.

It has been postulated that at bombarding energies above 0.4 GeV, meson production and reabsorption play important roles in transferring energy from an incident proton to a target nucleus. The availability of high energy ($\approx$2 GeV/amu) heavy ions from the LBL Bevalac made possible tests of the role of mesons in the reactions of these ions with target nuclei. Data for the spallation of copper by 0.28 GeV/amu ^{14}N (below meson threshold) and 2.1 GeV/amu ^{12}C (above meson threshold) are compared in Fig. 4. The points and solid curves show the observed yield ratios for the heavy ions. None of these ratios deviates markedly from unity, i.e., increase of the heavy ion bombarding energy from values (per amu) below meson production threshold to those above does not have a significant effect on the relative cross sections for production of given reaction products.

This is in striking contrast to the case of proton bombardment, the results of which are shown by the dashed curve in Fig. 4.

Nuclear Spectroscopy

A unique Medium Energy Intense Neutron Facility (MEIN) has been constructed which utilizes the surplus beam from the AGS injector linac. Reactions of the 200-MeV protons in a water-cooled copper beam stop serve as a copious source of energetic neutrons. For an incident beam current of 100 μA, the useful flux of neutrons having energies between 25 and 200 MeV is 1.3×10^{10} n/cm^2/sec. This facility has been used to produce by the (n,2pn) reaction the four new neutron-rich nuclides listed in Table I. Each of these is the heaviest known isotope of its element. While such isotopes could have been produced by other means [e.g., the (p,3p) reaction], the use of neutrons gives enhancement of the desired neutron-rich products by factors of from 10 to 100 over interfering neutron-deficient species which, in turn, considerably simplifies measurements of decay properties of the new isotopes. Decay schemes of nuclides far from stability are useful as constraints on theoretical models of nuclear structure and in tests of nuclear mass equations. Decay properties of some of the isotopes which can be produced in the MEIN facility may also be important in relation to understanding nucleosynthesis of elements in stars.

Table I

New Neutron-Rich Isotopes Produced at BNL

Isotope	Production reaction	Half-life
^{62}Fe	^{64}Ni(n,2pn)	68±2 sec
^{190}W	^{192}Os(p,3p) and ^{192}Os(n,2pn)	30.0±1.5 min
^{196}Os	^{198}Pt(n,2pn)	35.0±0.5 min
^{230}Ra	^{232}Th(n,2pn)	93±2 min

STUDY OF DYNAMIC SCALING BY NEUTRON SCATTERING IN MAGNETITE

Critical phenomena embrace a wide variety of phase transformations in which a change of state occurs without a latent heat. Such behavior can be found, for example, in liquid-gas systems, magnetic systems, order-disorder alloys, ferroelectrics, and superconductors. It has been known for many years that, at the transition point, these systems exhibit very similar discontinuities in such quantities as specific heat, compressibility, and magnetic susceptibility. The essential features of critical behavior are easily seen and conveniently studied in magnetic systems. In a simple ferromagnet, for example, spins are aligned at low temperatures by short-range interactions. As the temperature is raised some spins are reversed, breaking the alignment, and making it easier to reverse still others. This produces a cascade which causes the net magnetization to disappear at the critical point. Just above this point (Curie temperature) spin clusters remain and fluctuate in size with time, but there is no net, or long-range, order.

Spin clustering, or short-range order, gives rise to strong diffuse scattering of neutrons, analogous to critical opalescence in fluids. The time dependence of the local order produces an energy dependence of the critical scattering. The ability to detect both spatial and time-dependent correlations among spins has made neutron scattering one of the most important tools for the study of critical phenomena.

Whereas no detailed theoretical picture of the critical range is presently available, some general conjectures have served to provide guidelines for interpreting critical behavior. One such proposal is the hypothesis of Dynamic Scaling, whose great utility is that it makes possible calculations of some properties in the critical region from those in regions where they are understood. Dynamic Scaling postulates the existence of a single characteristic frequency which describes the decay in time of the spontaneous fluctuations constituting the short-range order. The important features of this frequency are assumed to depend only on a range parameter which is the average distance over which spins are correlated in the short-range order region.

The Dynamic Scaling assumption received its first convincing experimental confirmation in neutron scattering studies at this laboratory on the antiferromagnet $RbMnF_3$. Further confirmation has been obtained here and elsewhere by neutron studies of several ferromagnets and other antiferromagnetic systems. The case of magnetite (Fe_3O_4) is interesting because it is the prototype of a large number of ferrimagnetic materials in which a net macroscopic moment is produced by microscopic antiferromagnetic interactions. In this case, Dynamic Scaling predicts that the energy spectrum of the scattered neutrons should exhibit a width proportional to the 5/2 power of the momentum change of the neutron on scattering.

Earlier work of others, using natural crystals, indicated that this dependence was given by the exponent 1.6 which is close to the value 1.5 expected for a pure antiferromagnet. Our investigation, however, carried out with a very pure and stoichiometric synthetic specimen, gave the value 2.3, thus reestablishing confidence in the general applicability of Dynamic Scaling.

STRUCTURAL CHEMISTRY

Neutron diffraction has a unique role as an experimental technique in structural chemistry for determining the position of hydrogen atoms accurately. It is being used alone or in combination with x-ray diffraction to study a variety of compounds where a knowledge of the exact location of the hydrogen atoms is crucial to understanding the nature of the chemical bonding and the relationship between structure and chemical properties. Such compounds include transition metal hydride complexes, hydrogen-metal alloy systems, hydrates, carbohydrates and other biochemically important molecules. The nature of the chemical bonding in certain metal-hydrogen complexes can be understood only when the structure of the metal-hydrogen bonds is accurately known. This is being determined in compounds such as $H_3Ta(\pi\text{-}C_5H_5)_2$, and $H_3Ni_4(\pi\text{-}C_5H_5)_4$.

The hydrogen-metal alloy systems of V, Nb and Ta have been studied and are providing basic information regarding the location of hydrogen in the metal lattices and mechanisms for the diffusion of hydrogen in metals.

Neutron diffraction studies on carbohydrates have revealed, for the first time, a definite relationship between the H. . .O hydrogen-bond distances and the type of hydroxyl-to-oxygen interactions in some simple monosaccharides.

A combination of x-ray and neutron diffraction techniques is being used to examine the electron density in hydrogen bonds. These investigations show that the electrostatic picture of the hydrogen bond as originally advanced by Pauling and others is basically correct, and that charge rearrangement occurs upon hydrogen-bond formation, thereby strengthening the interaction.

Computers and computer graphics are also an integral part of the Structural Chemistry program. Interactive computer graphics are used as a visual aid in the analysis of structural results. Structural data bases are being developed to make possible rapid extraction of information from the crystallographic literature. The Protein Data Bank, a library of data on macromolecular structures, is maintained at BNL, and work has begun to implement network access to the Structural Data File for organic and organometallic compounds.

THEORETICAL CHEMISTRY

The techniques of theoretical chemistry, in conjunction with large-scale digital computers, have rapidly evolved in recent years into very powerful research tools that complement experiment in chemical investigations. At BNL these theoretical methods are being used to study a wide variety of chemical problems at the most fundamental molecular level. The results have been used to interpret experimental data, and they have been of much value in suggesting lines of further experimental work. An indispensable tool in this work is BNL's new CDC Cyber 70/76 computer, a machine of unsurpassed computational capacity.

The current research involves two stages: (1) the generation of quantum mechanical potential energy surfaces, both *ab initio* and semi-empirical; and (2) the use of these surfaces in classical or quantum mechanical models of chemically important structural and dynamical properties. Several recent advances in methodology have made it possible to treat theoretically chemical problems considerably more complicated than hitherto possible. Among these advances are: the incorporation of long-range solvation effects into quantum mechanical models of discrete molecular clusters, thus allowing an examination of the degree of chemical, as well as physical, continuity between gas and liquid phases; the use of so-called pseudopotentials to simulate the effects of inner-shell (non-valence) atomic electrons in atoms of high atomic number, making it possible to apply accurate *ab initio* techniques to these atoms; and the extension of theoretical and computational techniques to treat the dynamics of more complicated processes.

Examples of the kinds of problems being worked on at BNL are the following: (1) Detailed quantum mechanical models have been constructed for treating the equilibrium and transport properties of excess protons and electrons in polar media. A variety of predictions based on these models have been verified by magnetic resonance and neutron diffraction experiments, and it has been demon-

strated that solvent shell reorganization plays a key role in the activation step for proton and electron transfer in aqueous solution. (2) By a combination of potential energy and dynamical calculations for the prototype $C + H_2$ and $O + H_2$ reactive systems, detailed predictions have been made regarding the effects of kinetic energy and atomic spin state on the competition between insertion and direct abstraction mechanisms. These predictions have stimulated new experimental hot-atom studies in this Department, with results thus far consistent with the theory. (3) Dynamical calculations are also under way for the various electron, proton, and atom transfer processes that are possible in the $H_2 + H_2^+$ system and its isotopic variants. In the above studies, computer-generated movies have played a crucial role in revealing important features of the reaction dynamics.

STUDIES OF TRANSIENT IONS AND FREE RADICALS

The Chemistry Department has two electron accelerators, a 2-MV Van de Graaff and a 2-MeV Febetron, both of which deliver pulses of radiation to samples in times sufficiently short that unstable species produced can be observed. Such species may be produced in other ways (in chemical reactions or by photolysis, as examples) but often pulse radiolysis offers the simplest way to study them.

An example is the very reactive intermediate valence state of thallium, Tl(II), which, though formed by ordinary chemical reactions in solution, disappears so rapidly by reaction that its existence can only be inferred indirectly from conventional kinetic studies. Pulse radiolysis of solutions containing Tl(I) and Tl(III) produces sufficient Tl(II) to study directly. It was found from these studies that Tl(II) is a better oxidizing agent than Tl(III) and a better reducing agent than Tl(I). It was also found that Tl(II) forms complexes with anions much as Tl(III) does, though they are somewhat weaker than the corresponding Tl(III) complexes.

Proton-Water Complexes

It is possibile to obtain a better understanding of the hydrogen ion in water by studying simpler, but unstable, proton-water complexes in the gas phase. The proton is strongly bound to one water molecule forming H_3O^+, hydronium ion. This ion can be hydrogen-bonded to three other water molecules, which constitute the inner coordination sphere, and which, in turn, can be hydrogen-bonded to an outer coordination sphere. The shape of the potential energy function describing the OH bonds of the central H_3O^+ can be determined from the OH stretching bands in the infrared spectrum: the flatter the function, the lower the band frequency. Consequently, much can be learned about the hydronium ion by isolating and studying individual hydrates. Some of the second sphere hydrates can be produced by pulse radiolysis of an atmosphere of argon containing traces of water vapor. The low ion concentrations obtainable (10^{11} per cm^3 for 10^{-5} sec) and the weak nature of infrared absorptions make spectral measurements difficult. A signal averaging technique, in which absorptions from 10,000 pulses are added together, was developed to allow detection of very small absorptions. Infrared spectra were obtained for $H_9O_4^+$, $H_{11}O_5^+$, and $H_{13}O_6^+$. Other workers had measured the OH stretch frequencies in crystals or in SO_2 solutions containing H_3O^+, $H_5O_2^+$, $H_7O_3^+$, and $H_9O_4^+$ and found a progression to lower frequency for the addition of the first three water molecules. The gas phase experiments show that this trend is reversed as water molecules are added to the second sphere. The absorption bands move to higher frequency with each subsequent addition approaching, again, the spectrum of H_3O^+. This effect has been predicted in a theoretical study at Brookhaven.

Reaction Intermediates of Biological Interest

The technique of "stopped-flow radiolysis" has been developed to study relatively slow reactions of free radicals (mean reaction time 0.01-10 seconds). The radical is generated in a solution by flowing it through a fast-electron beam; the solution is then mixed with one containing a reagent for the radical to react with; the mixed solution flows next through an optical cell. When the flow is suddenly stopped, the progress of reaction to completion in the cell is observed by the accompanying change in optical properties. The chemistry of the biologically important oxygen negative ion radical (O_2^-) is being studied by this method. O_2^- is rather inert toward organic compounds but reacts readily with many compounds of transition metals, such as copper and iron. This type of reaction of O_2^- may be involved in the action of metal-containing oxidative enzymes. The method is also used to study reactions of the ascorbate radical formed in the reactions of vitamin C.

PROPERTIES OF EXCESS ELECTRONS IN HYDROCARBON LIQUIDS

Of the basic processes involved in radiation effects, the least well understood is the behavior of electrons generated in liquids or amorphous solids by ionization. In polar liquids, a shell of oriented molecules forms around the electron, which is said to be "solvated"; its physical properties resemble those of a molecular ion. In monatomic liquids such as liquid argon and in some other liquids such as methane, the electron is said to be "quasi-free"; it moves through the liquid as though it were in a dilute gas or in the conduction band of a semiconductor. The important measurable physical properties of the electron are its mobility (which determines the conductivity); its energy V_0 in the mobile state, relative to the energy of an electron in a vacuum or a dilute gas; and (for a solvated electron) its optical absorption. Electron mobilities in liquid hydrocarbons were found to vary by factors of several hundred, even between isomers very similar in other physical properties; qualitatively, the more nearly spherical the molecules of the hydrocarbon, the higher the mobility. Irregular molecular shapes seem to produce weak potential minima in which the electron can be trapped or "solvated," though remaining in thermal equilibrium with the quasi-free state; the mobility is then very sensitive to the trap depths, which depend on molecular shape. The values of the quasi-free state energy V_0 in hydrocarbons also depend on molecular shape, being more negative the more nearly spherical the molecules. Theory suggests that multiple scattering in an irregular geometry leads to a shortening of the effective wavelength of the electron and hence an increase in its energy content: $V_0 = P + T$, where P is the polarization energy of the liquid by the electron (and is nearly the same for all hydrocarbons), and T is the kinetic energy due to multiple scattering. No satisfactory quantitative theory of these shape effects has yet been formulated.

The *chemical* properties of the electron can be expressed in terms of its reaction rates with various molecules. Extensive measurements have shown a remarkably good correlation in liquid hydrocarbons between the electron reaction rate constant k, the gas-phase reaction cross sections σ for the same molecule, and the energy level V_0 of the electron in the liquid. V_0 can be varied by changing the temperature in a given solvent or by changing the solvent. It is found that k for reaction with a particular molecule is a function of V_0 only; it typically increases with decreasing V_0, reaches a maximum at $V_0(\max)$ and then declines, even though the mobility continues to increase. In the gas phase, σ, determined as a function of the kinetic energy E of the electron, is found to have a maximum at a certain value E(max), explained by postulating a resonance between the frequency of the electron wave and that of certain vibrations in the molecule. For several molecules, $V_0(\max) = E(\max) - 0.6$ eV. The number 0.6 eV is presumably the value of the term P.

An interesting effect is found in solutions of carbon dioxide in hydrocarbons. An equilibrium exists between the electron, the CO_2 molecule and the ion CO_2^-. Measurement of the equilibrium constant in different hydrocarbons as a function of temperature gives estimates of the free energy and entropy of the electron, which agree with estimates based on V_0 and on the temperature effects on the mobility.

INORGANIC SOLUTION KINETICS AND PHOTOCHEMISTRY

When a molecule in its normal ground state absorbs light, an excited state of the molecule is formed. The excited state may be destroyed in several ways: it may return to the original ground state molecule either by light emission or heat production or it may undergo a chemical reaction. Such light-induced (photochemical) reactions which may be used to convert and store solar energy in useful forms (fuel or electricity) always compete with heat production and light emission which result in no useful energy conversion. Furthermore, "back-reaction" of the newly formed products of the photochemical reactions may give back the original starting materials and lower the efficiency of energy conversion. Thus, our work focuses on discovering ways to favor the photochemical reactions over heat production and light emission, and to minimize energy storage losses resulting from "back-reactions."

Electron-transfer (oxidation-reduction) reactions are the most useful types of photochemical reaction for solar energy conversion and storage. Certain metal complexes strongly absorb light in the visible region and readily donate electrons to or accept them from suitable substrates. Metal complexes, then, may be useful mediators for the

collection and storage of solar energy, and the photochemistry of metal complexes is being investigated in this laboratory.

The series of luminescent polypyridineruthenium(II) complexes strongly absorb visible light ($\lambda_{max} \sim 450$ nm) and undergo either oxidation [Eq. (1)] or reduction [Eq. (2)] with potentials that depend upon the ring substituents.

$$Ru(bipy)_3^{2+} \rightleftharpoons Ru(bipy)_3^{3+} + e \quad (1)$$

$$Ru(bipy)_3^{2+} + e \rightleftharpoons Ru(bipy)_3^{+} \quad (2)$$

The charge-transfer excited states of these complexes [$^*Ru(bipy)_3^{2+}$] are rather long lived ($\tau = 0.1\text{-}5.0$ μsec in water, 25°) and decay, in part, by the emission of light of ~600 nm. The excited state molecules are expected to be both stronger reductants [Eq. (4)] and stronger oxidants [Eq. (5)] than the ground state molecules by the excitation free energy [Eq. (3)] of 2 electron volts.

$$Ru(bipy)_3^{2+} \rightleftharpoons {}^*Ru(bipy)_3^{2+} \quad (3)$$

$$^*Ru(bipy)_3^{2+} \rightleftharpoons Ru(bipy)_3^{3+} + e \quad (4)$$

$$^*Ru(bipy)_3^{2+} + e \rightleftharpoons Ru(bipy)_3^{+} \quad (5)$$

Many features of the chemistry of this excited state as a reducing agent have been characterized. In general, the excited molecule acts as a very strong "outer-sphere" reducing agent; that is, no bonds are broken or made when it transfers electrons to the oxidant. Furthermore, the reactivity patterns observed for its reactions with oxidants are as predicted from theories of electron-transfer reactions for ground state molecules. One of the oxidants of particular interest is aqueous iron(III) (Fe^{3+}). By using a flash-photolysis technique, $Ru(bipy)_3^{2+}$ may be very rapidly excited to $^*Ru(bipy)_3^{2+}$. Normally the excited state returns to the ground state by light emission and heat production; but, when Fe^{3+} is present, reaction(6), in which the excited state is oxidized by Fe^{3+}, also occurs. The products of the excited state reaction, $Ru(bipy)_3^{3+}$ and Fe^{2+}, subsequently undergo a comparatively slow "back-reaction" [Eq. (7)] in which the ground-state reactants are reformed.

$$^*Ru(bipy)_3^{2+} + Fe^{3+} \rightarrow Ru(bipy)_3^{3+} + Fe^{2+} \quad (6)$$

$$Ru(bipy)_3^{3+} + Fe^{2+} \rightarrow Ru(bipy)_3^{2+} + Fe^{3+} \quad (7)$$

This back-reaction is so slow that appreciable steady-state concentrations of $Ru(bipy)_3^{3+}$ and Fe^{2+} accumulate when a solution containing $Ru(bipy)_3^{2+}$ and Fe^{3+} is illuminated continuously. This accumulation of photoproducts leads to photogalvanic effects, and voltages on the order of 200 millivolts have been observed when $Ru(bipy)_3^{2+}$/Fe^{3+} solutions are irradiated in suitable electrochemical cells.

The charge-transfer excited state of $Ru(bipy)_3^{2+}$ also acts as an outer-sphere oxidizing agent. In flash-photolysis experiments, the species $Ru(bipy)_3^{+}$ has been produced from the reduction of $^*Ru(bipy)_3^{2+}$ by aqueous europium(II) (Eu^{2+}) [Eq. (8)] and identified by its absorption spectrum.

$$^*Ru(bipy)_3^{2+} + Eu^{2+} \rightarrow Ru(bipy)_3^{+} + Eu^{3+} . \quad (8)$$

Fundamental studies of the kind described here are of considerable practical import in solar energy conversion inasmuch as complexes like $Ru(bipy)_3^{2+}$ may be of use in new photogalvanic cells and as mediators in the photodissociation of water.

LASER-INDUCED CHEMICAL REACTIONS FOR ISOTOPIC SEPARATION

Almost as soon as isotopes were discovered, attempts were made to use photochemical reactions as a method of isotope separation. This approach is based on the fact that atomic and molecular energy levels depend on atomic masses, leading to observable isotopic differences in infrared, visible, and ultraviolet spectra. If a single isotopic species of a molecule can be excited, an appropriate chemical reaction that selects excited molecules will lead to a product containing only one isotope. Within the past few years, interest in such photochemical methods has been revived because of the availability of lasers – sources of very high intensity and spectrally pure light.

In other ERDA laboratories, the use of lasers for the enrichment of ^{235}U is being intensively pursued. According to present estimates, the very large isotope enrichment factors potentially attainable in photochemical processes could make it possible to produce ^{235}U for nuclear power reactors with large reductions in capital and operating costs. Experimental work at Brookhaven is focused on a search for photochemical processes that will be useful for the separation of lighter isotopes such as $^{12}C/^{13}C$, or $^{16}O/^{17}O/^{18}O$; it is directed also at obtaining basic knowledge that can be extended to separation of other elements such as

uranium. Three general areas currently being investigated, and an example of each are as follows:

(1) Enhancement of the rate of chemical reaction by the use of vibrationally excited reactants – With a CO_2 laser that emits ~1 joule pulses at a wavelength of ~10 μm, gaseous ozone (O_3) is vibrationally excited. By appropriate selection of the laser wavelength, it should be possible to excite ozone containing the ^{18}O isotope. The rate at which these vibrationally excited molecules (O_3^v) disappear (usually by energy transfer in collisions) can be followed by observing infrared fluorescence from the energetic molecules. The admixture of a small amount of oxygen atoms has been shown to increase this disappearance rate markedly, perhaps because of the chemical reaction

$$O_3^v + O \rightarrow 2O_2 .$$

If this is the path, then the rate constant is increased by a factor of 150-1500 over that for the unexcited ozone molecule. Work is under way to determine whether chemical reaction, rather than energy transfer, is responsible for the rapid decrease in the O_3^v population.

(2) Two-photon molecular dissociation by consecutive absorption of infrared and visible radiation – The carbon dioxide laser can be used to excite selectively one isotopic species of chlorine dioxide (ClO_2) while the other isotopic species remains in the vibrational ground state. A subsequent pulse of higher-energy light from a tunable dye laser (at about 400 nm) will provide enough energy to dissociate the vibrationally excited molecules only. Chemical reactions will then remove the molecular fragments. At present, the vibrational excitation and relaxation processes have been studied, and work is under way on the dissociation process.

(3) Multiple-photon absorption of infrared radiation leading to unimolecular reaction – Here and in other laboratories it has been found that molecular fragmentation can result from the isotopically selective absorption of a very intense infrared laser pulse. As many as 40 photons must be absorbed by a single molecule for its energy to reach the level needed for bond breaking, and the mechanism for this is not well understood. In this laboratory, unimolecular fragmentation and isomerization reactions that are well-characterized from conventional kinetic experiments are being sought as possible candidates for this type of multiple-photon process. The reactions

$$CH_3NC \rightarrow CH_3CN$$

and

$$\text{cyclo-}C_4F_8 \rightarrow 2C_2F_4$$

have been induced by pulses from the carbon dioxide laser, and the possibility of isotopic enrichment is now being investigated.

GASEOUS ION CHEMISTRY AND ION-IMPACT PHENOMENA

Secondary electrons are produced in the bombardment of solid surfaces by large polyatomic molecular ions if these ions have sufficient velocities on impact. The study of the yields of such secondary emission provides a means of investigating energy transfer processes which generate extremely high local temperatures in solids and are associated with the production of many electrons per ion impact. An ion post-acceleration detection system has been developed to increase the kinetic energy of gaseous ions emerging from a mass analyzer to ~100 keV. Collision of these energetic ions with a metal surface produces secondary electrons which are focused onto a semiconductor detector. The post-acceleration detector system produces a pulse spectrum of electrons characteristic of the energetic projectile ion. Because this electron spectrum can be almost completely resolved from detector noise, the technique provides a very significant advantage in the detection of very weak ion currents produced in mass spectrometry and studies of gaseous ion chemistry (Fig. 5).

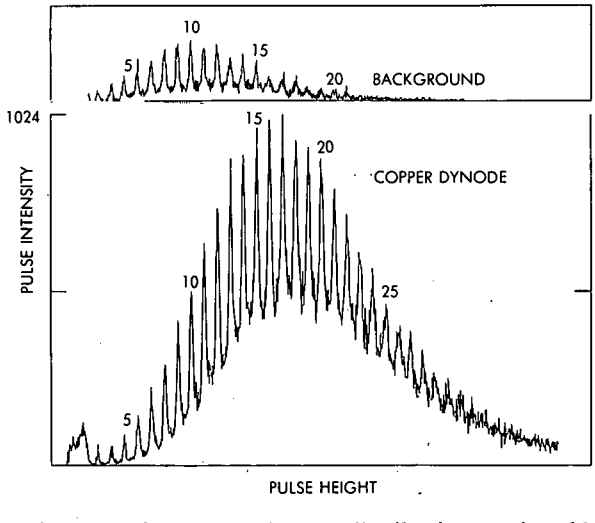


Figure 5. Secondary electron distribution produced by bombardment of a copper surface by $C_4H_5N^{++}$ ions.

The semiconductor detector post-acceleration system has been used in the study of the field desorption mass spectrum of glucagon, a peptide containing 29 amino acid residues. Molecules of this size and general class are difficult to evaporate, and only the combination of the field desorption technique and the high sensitivity of the detection system made possible a useful search for parent molecule ions. The study gave evidence for fragment ions containing as many as 18 amino acid residues, m/e~2100, but no parent molecular ions. This result provides some insight into energy transfer processes in field desorption ionization and it gives a rough measure of the upper size limit of underivatized peptides that can be successfully investigated by the field desorption technique.

APPLICATIONS OF RADIOISOTOPES TO MEDICINE

In recent years, in applications of radioisotopes to medicine increasing emphasis has been put upon their use in disease diagnosis. In principle, they provide means for the safe, non-invasive, and early detection of abnormalities in organ shape and function. To transform this to practice requires the design, development, and evaluation of new short-lived radiopharmaceuticals which will localize in specific organs and trace specific physiological functions. Such radiopharmaceuticals serve as more than simply diagnostic tools; they can also provide leads on the nature of the relation between structure and localization in a particular organ, which may make it possible in the future to tailor pharmaceuticals to the function one wishes to study.

At BNL the chemists involved in the multidisciplinary Nuclear Medicine Program have focused their attention on the design of new radiopharmaceuticals which incorporate isotopes of short half-life obtained at the BNL 60-inch cyclotron. Among the most interesting of these isotopes are nitrogen-13, oxygen-15, carbon-11, iodine-123, and fluorine-18. The shortness of their half-lives enables their use in diagnostic procedures with a minimum radiation dose to the patient. The radiations they emit can be analyzed with the help of certain new devices, to provide images of the organ or information on the function of the organ or tissue.

Recent work has involved the labeling of a dye, indocyanine green, with iodine-123 (13.3-h half life) for liver function studies. Clinical studies have been initiated with this radiopharmaceutical. A series of radio-iodinated dye analogs is being studied in animal models to determine the effect of molecular size on liver uptake and clearance.

Another aspect of the program involves the use of carbon-11 labeled amines to study a newly recognized function of the lung, namely its capacity to metabolize and regulate the concentration of substances in the blood stream, whether they are endogenous or come from exogenous sources. Carbon-11 is almost ideal for this purpose; its half-life is short, but not too short, and it can be incorporated in many organic substances of interest. Administration of trace amounts of these carbon-11 labeled substances to a patient allows one not only to visualize his lung, but also to assess lung function by following the rates of appearance and disappearance of the substance. Pictures taken after the administration of ^{11}C-octylamine in a human are shown in Fig. 6.

Another radiopharmaceutical soon to be clinically evaluated is a fluorine-18 (110-min half life) labeled sugar which, it is hoped, will provide a means for measuring regional brain metabolism in healthy and diseased individuals. Information of this kind may be valuable to the practicing physician in that it gives him more qualitative information as to how the brain is functioning in a particular disease state and puts him in a better position to choose the type of care required.

The preparation of the nuclides required for this radiopharmaceutical research and application is carried out at the BNL 60-inch cyclotron which serves as a core facility for this program.

TECHNIQUES FOR MEASUREMENT OF ENVIRONMENTAL POLLUTANT LEVELS

A very efficient method of sampling for airborne environmental pollutants is provided by Nature in the form of pine trees, as discovered recently by Clarence Gordon of the University of Montana. He found that a wide variety of atmospheric pollutants are efficiently picked up by live pine needles. By gathering pine needles from different locations and analyzing them for various pollutants by modern high-sensitivity techniques, the way that patterns vary in space and time can be followed. This natural sampling method was made to order for the Analytical Group of the Chemistry Department when they undertook studies of environmental pollution on Long Island in connection with

the Laboratory's environmental impact statement. They were immediately able to apply to large numbers of pine-needle samples (see map) the techniques of neutron activation and atomic absorption analysis and methods for data handling developed over the past 20 years in connection with their archaeological studies. Whereas, in the archaeological work, the aim had been to "fingerprint" ancient wares and their corresponding clay sources through determination of their trace element "profiles", in the environmental studies, the goal was to establish the change in these patterns with geographical location of the pine-needle source, and from this to infer variation in ambient levels of air pollution. In both cases, computer-based data-processing techniques must be employed to uncover the underlying structure and meaning in the large amount of multivariate data

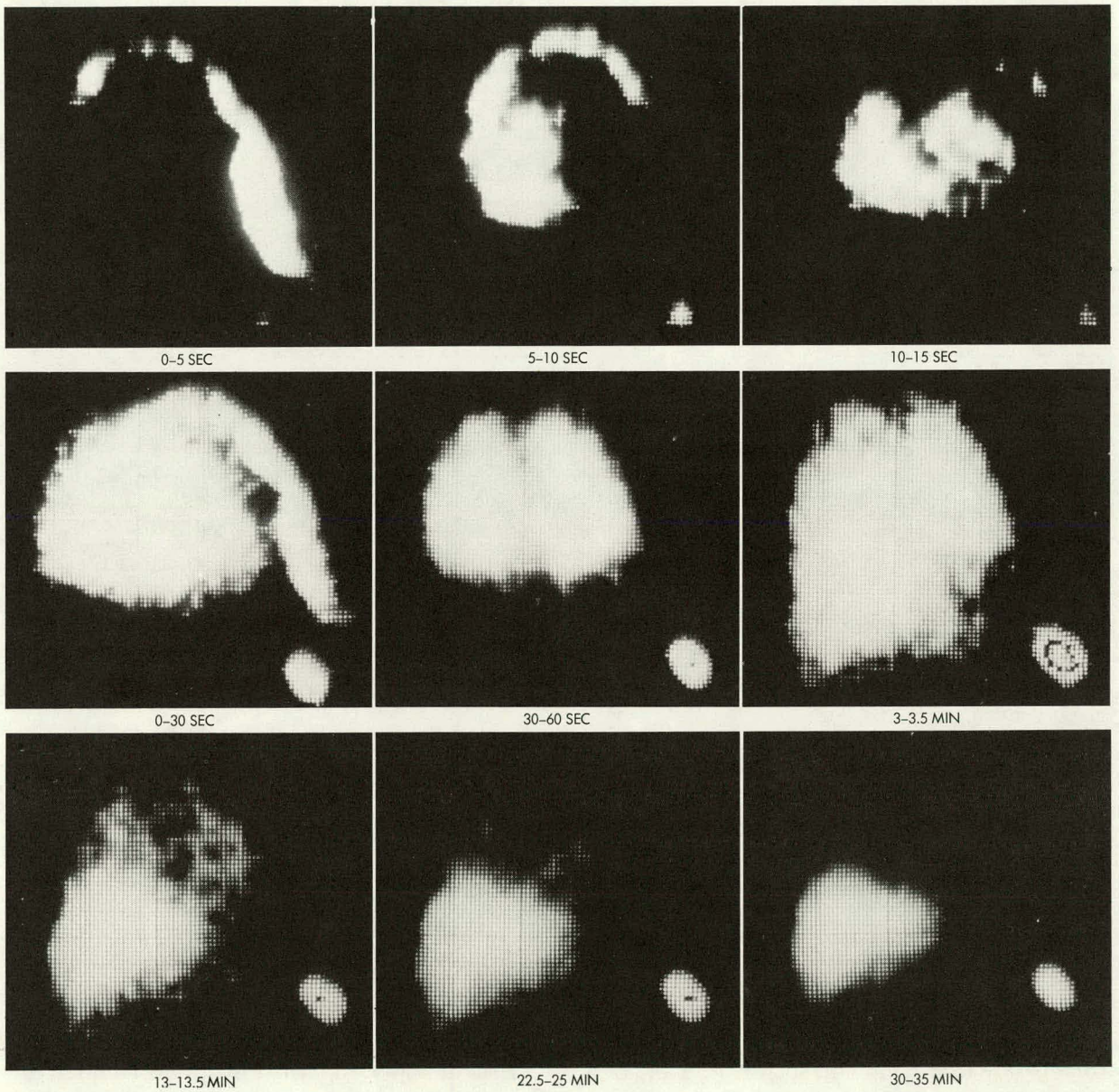


Figure 6. Dynamic monitoring of the upper torso of a normal male subject is made possible with the use of a gamma camera. In the first frame (0-5 sec) the site of injection and appearance of activity in the lung is visualized. After 13.5 minutes the carbon-11 metabolites have cleared the lung and appear in the liver. Thus the rate of lung intake and clearance of substances can be measured and the degree of dysfunction assessed.

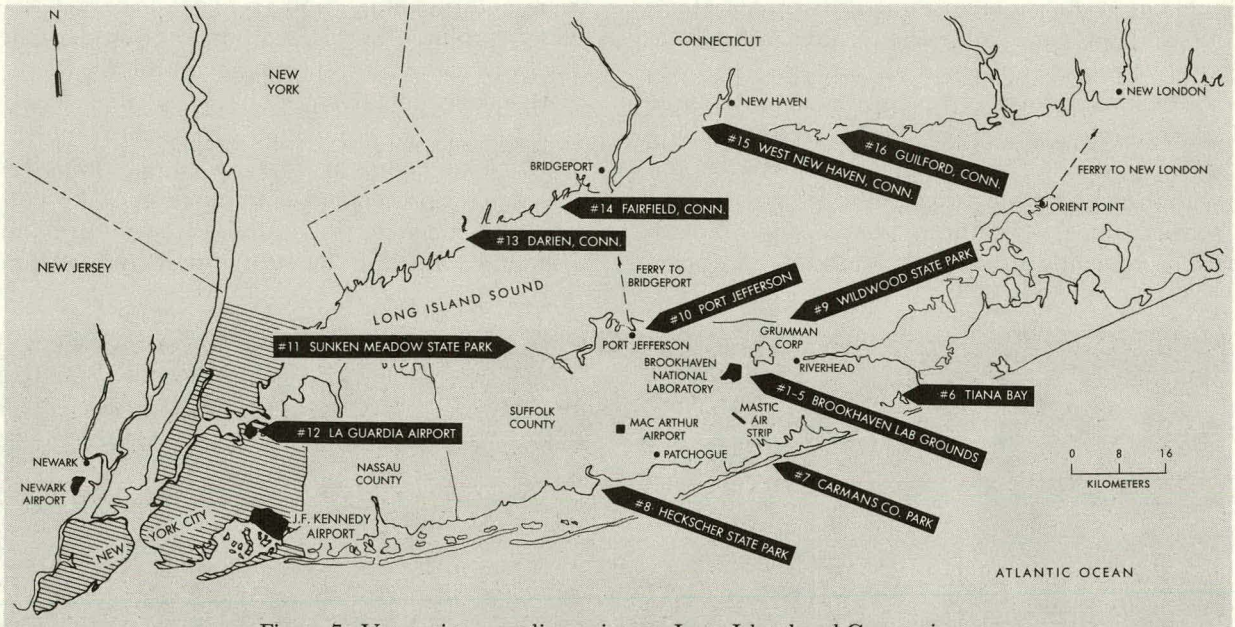


Figure 7. Vegetation sampling points on Long Island and Connecticut.

Table II

Environmental Pollution

Trace Elements Measured in Pine Needles by Neutron Activation Analysis and Atomic Assorption

Sampling location	Element concentrations – parts per million, except gold and mercury – parts per 10^9 (ppb)										
	Sodium	Thorium	Chromium	Manganese	Bromine	Antimony	Chlorine	Arsenic	Lead	Gold ppb	Mercury ppb
Port Jefferson	400	0.024	0.85	205	5.5	0.08	460	0.08	5.9	0.035	67
Wildwood State Park	210	0.036	0.60	233	5.0	0.05	371	0.18	6.4	0.027	58
Brookhaven (North Road)	200	0.045	0.92	390	10.0	0.08	n.d.	0.30	10.6	n.d.	53
Tiana	1740	0.080	1.52	106	15.5	0.16	2530	0.36	11.1	0.030	20
Carmans County Park	510	0.057	0.99	167	8.2	0.07	1010	0.18	6.8	0.031	90
Guilford, Conn.	110	0.012	0.59	657	4.2	0.05	n.d.	0.06	8.0	0.057	61
LaGuardia Airport	360	0.163	5.12	48	51	1.13	792	1.27	197.0	0.072	129

generated. The results (see Table II) showed that needles from trees growing near highways clearly contain vehicular pollutants such as lead and bromine (tetraethyl lead bromide) while those growing in exposed locations near the sea contain sodium, bromine, and chlorine from salt-spray. A set of needles growing on a tree at LaGuardia Airport, New York City, showed lead, arsenic, antimony, bromine, chromium, and thorium levels anywhere from five to thirty times those found in corresponding needles gathered on Long Island at points far from the city. Clearly, this new technique has great potential for application to environmental pollution studies.

LIFE SCIENCES

BIOLOGY DEPARTMENT

INTRODUCTION

Research in modern biology emphasizes our need to understand in physical and chemical terms the life processes of cells and organisms. Such fundamental knowledge is essential for a rational approach in areas of common concern that relate to biology, such as human health, agriculture, and protection of the environment.

The Biology Department research effort falls into three logical groupings. The first of these, acknowledging that structure at the anatomical or molecular level determines form and function, consists of research programs dedicated to exploration of biological structures by a wide range of advanced biochemical and biophysical techniques. Since replication of these structures depends on genetic material, considerable effort centers on DNA synthesis and the mechanism by which it determines the nature of RNA and protein.

Present day power sources and the utilization of fossil fuels engender environmental intrusions in the form of chemical pollutants and ionizing radiations. The second group of programs seeks to determine how these byproducts modify, usually in harmful fashion, the organization of biological structures, and how the organism is able to cope with some insults by active repair mechanisms.

The third group of research programs in the Biology Department seeks understanding of the biochemistry and physiology of plants. In photosynthesis, non-ionizing solar radiation is transduced to provide food and fibre. In addition to its agricultural relevance, photosynthesis research is directed toward development of novel solar power sources. The structures of light-harvesting pigments in photosynthetic bacteria, algae, and marine phytoplankton are being elucidated, as is the complex mechanism by which day length regulates plant growth and development.

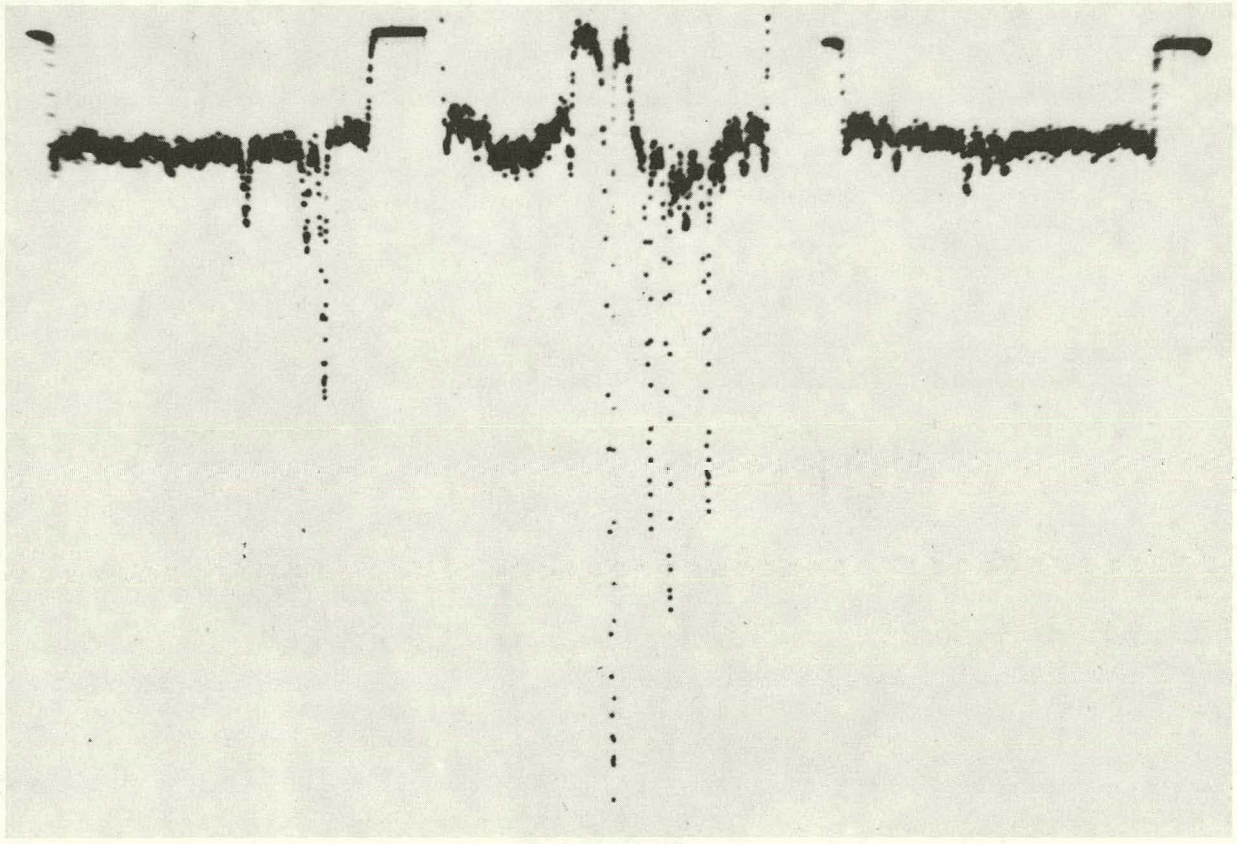


Figure 1. Simultaneously collected data from a cadmium derivative of myoglobin. The three segments cover an acceptance angle of 82° with two 8° gaps separating the segments. The vertical axis displays intensity. Eleven out of 16 possible reflections are measured. The central trough is caused by the beam stop and shows the partially attenuated direct beam.

NEUTRON SCATTERING ANALYSIS OF BIOLOGICAL STRUCTURES

Measurements of neutron scattering permit the elucidation of structural details not amenable to exploration by conventional x-ray crystallography. Neutron diffraction studies are made possible at Brookhaven by the presence of the High Flux Beam Reactor.

Neutron scattering studies on the oxygen binding protein of muscle, myoglobin, have been extended to determine water density and bound water in the interstitial space. To improve such protein structural studies, a 3-segment position-sensitive linear counter system was developed, decreasing data collection times by a factor of seven. The different neutron-scattering powers of hydrogen and deuterium were used to determine the structures of a number of large biological systems including retinal rods, the light transducing mechanism of the eye, and purple membrane – an energy transducing complex found in bacteria.

Low angle solution studies with differentially hydrogen- or deuterium-labeled ribosomes have revealed the location and shapes of six different proteins.

SUPRAMOLECULAR STRUCTURE

Dichloromethane, an industrial solvent, prevents and reverts the formation of abnormal red blood cells commonly called sickle cells. X-ray diffraction binding studies have elucidated the attachment site of dichloromethane to hemoglobin molecules, thus localizing the molecular interactions responsible for sickle cell formation. These studies suggest that dichloromethane or similar inhalation anesthetics might have clinical application in the prevention and treatment of sickle cell anemia.

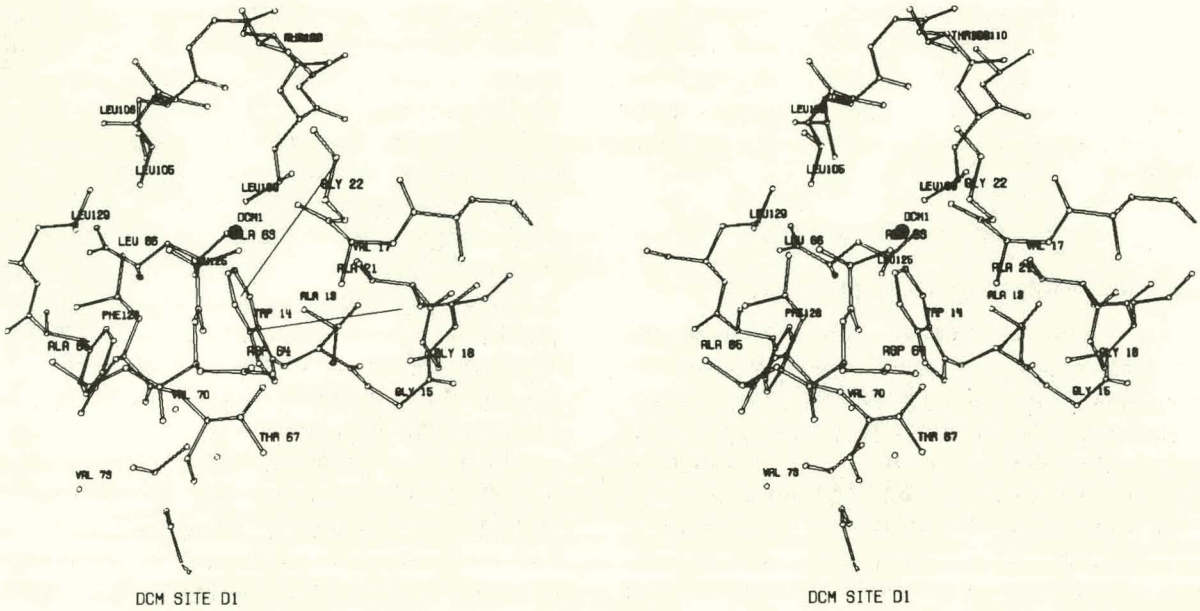


Figure 2. Stereoscopic drawing of the dichloromethane binding site to the α chain of hemoglobin. Due to the presence of dichloromethane, tryptophane 14 α is expelled from the interior causing stereochemical changes preventing the association of hemoglobin S into helical fibers.

ALLOSTERIC ENZYMES – ASPARTATE TRANSCARBAMYLASE

Much of the control of cellular metabolism is achieved through allosteric proteins. Binding of a signal molecule changes many of the properties of the protein, e.g., enzymatic activity or binding to DNA, allowing the signal molecule to switch different biochemical pathways on or off. Much effort has been directed at finding how the signal molecule changes the protein's properties. A most influential hypothesis, due to Monod, Wyman & Changeux, proposes that the allosteric protein exists in two activity states, differing in the arrangement of subunits, and that the signal molecule acts by changing the equilibrium between these states. Tests of this hypothesis have been hampered by the difficulty of finding the subunit arrangement of a protein in solution. Aspartate transcarbamylase, a much studied allosteric enzyme, gives a very different X-ray scattering pattern in solution after activation by substrate analogues. This pattern change gives a direct measure of the change of subunit arrangement of the enzyme, and is now being used to investigate the number and structure of different subunit arrangements present in solution, the effects of different substances on the equilibrium between them, and the speed and pathway of their interconversion.

PROTEIN STRUCTURE AND FUNCTION

The anticipated greater dependence on coal as an energy source requires that attention be given to a possible increase in carcinogenesis and in degenerative effects on the lungs that may accompany the mining, and utilization of coal. Proteases are considered to be involved in these health problems due to a derangement of their normal balance by noxious influences leading to a loss of control.

To understand how proteases function, a new type of protein chemistry known as affinity labeling has been developed. Small reagents are designed to be like normal substrates but, in addition, to be capable of attaching themselves to functional groups of enzymes by forming covalent bonds. The enzyme is thus inactivated, and the essential group can be identified. A variety of proteolytic enzymes, which function in blood coagulation, clot lysis, hormone formation, and other regulatory processes, were studied. The results show that although the various enzymes are different molecular entities, they are fundamentally similar catalysts. Because the inactivation of a

given proteolytic enzyme may be of therapeutic usefulness, the ability to devise a reagent capable of selective inactivation *in vivo* is another goal of this research. It was found that considerable specificity of inhibition can be achieved with the synthetic reagents.

ELECTRON MICROSCOPY

Scanning Transmission Electron Microscopy

The scanning transmission electron microscope (STEM) is superior to conventional electron microscopes for producing images of unstained biological molecules and single heavy atoms with minimum alteration of the specimen by radiation damage. The prototype STEM built at the University of Chicago demonstrates a 3-Å resolution and was able to detect single atoms as light as silver. This instrument was also used to observe and "weigh" single unstained DNA molecules and virus particles by taking advantage of the quantitative relationship between electron scattering intensity and mass.

The Brookhaven STEM is designed to overcome many of the practical difficulties of the prototype while providing higher performance (2 Å resolution) and new features such as the ability to examine frozen specimens. The major construction was performed at Brookhaven and the instrument is now going into operation in the Biology Department where it will be used jointly by Brookhaven and visiting scientists under the NIH Biotechnology Resource program.

The STEM will be used mainly for observing biological molecules which have heavy atoms attached to specific sites. The localization of these sites within the molecule or assembly of molecules will give structural information such as the se-

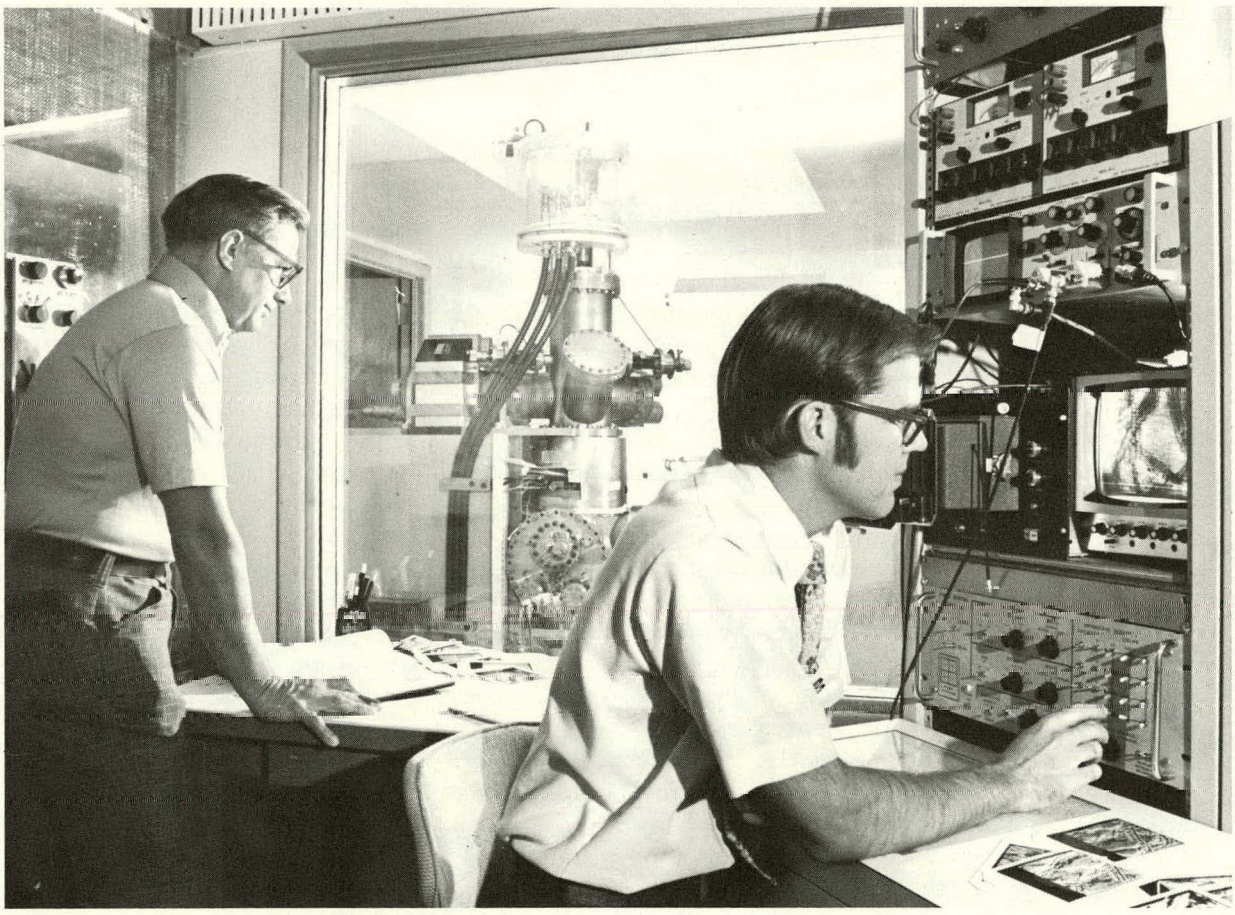


Figure 3. Operator (right) views the image produced by the STEM, located in a soundproof enclosure (rear). The image on the TV monitor is of tobacco mosaic virus.

quence of bases along a DNA strand, the location of the active site in an enzyme, or the symmetry of subunits in a virus particle. This approach should allow direct visualization of the structure at a resolution almost an order of magnitude higher than is possible with conventional electron microscopes.

Fluorescence Electron Microscopy

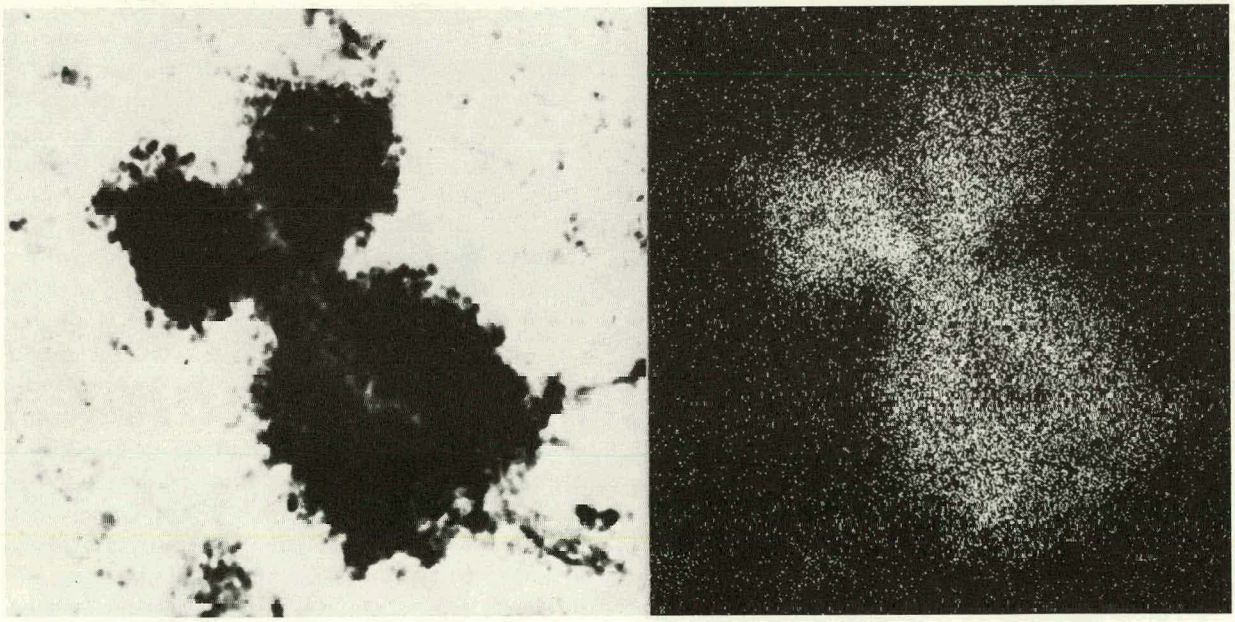
In the usual methods of electron microscopy the image created is descriptive of electron scattering power as it varies from point to point in the specimen, or of secondary electron emission coefficient for the specimen's surface. In fluorescence electron microscopy image light and shade represent the number of fluorescent photons emitted from each point of the object as the electron beam systematically scans it. The wavelength of fluorescent light is characteristic of the emitting biological molecule, e.g., blue-green for DNA and ultraviolet for protein. Therefore wavelength selection can provide an image showing only one molecular species. In the future several different wavelengths may be recorded simultaneously, permitting the determination of the space relationships of different identified species.

Figure 4 shows a DNA fluorescence elctron micrograph of a hamster chromosome and for comparison a conventional transmission electron micrograph. Fluorescence space resolution is so far limited to about 200 Å. In the future, specimens will be maintained at liquid helium temperature, and the resolution in localization of identified molecules may approach the theoretical limit of 20 Å.

Fine Structure of Plant Surfaces

The scanning electron microscope can be used to observe fine surface details of a variety of materials by forming images from the collected secondary electrons. In an examination of marijuana glands, three and possibly four types were distinguished on the surfaces of leaves and floral parts. By knowing their distribution it will be possible to collect the contents of the specified types of glands and analyze their chemical constituents. The method of visualizing fresh parts of plants in the scanning electron microscope, as used in the study of plant glands, has been examined with the aim of extending its usefulness. It was found that desiccation, which takes place in the high vacuum of the specimen chamber, can be arrested and problems of electron beam damage and electron charging can be alleviated, if the sample is frozen in

Figure 4. A hamster chromosome about 2.5 microns long is shown on the left by conventional electron microscopy and on the right by the fluorescent light it emits on being struck by a scanning electron beam. The color of the fluorescent light (not shown here) identifies the constituent of the chromosome which is emitting the light (here DNA). If this technique can be pushed to the very high magnification limit it will establish the detailed space relationship of DNA to other constituents of the chromosome such as histones.



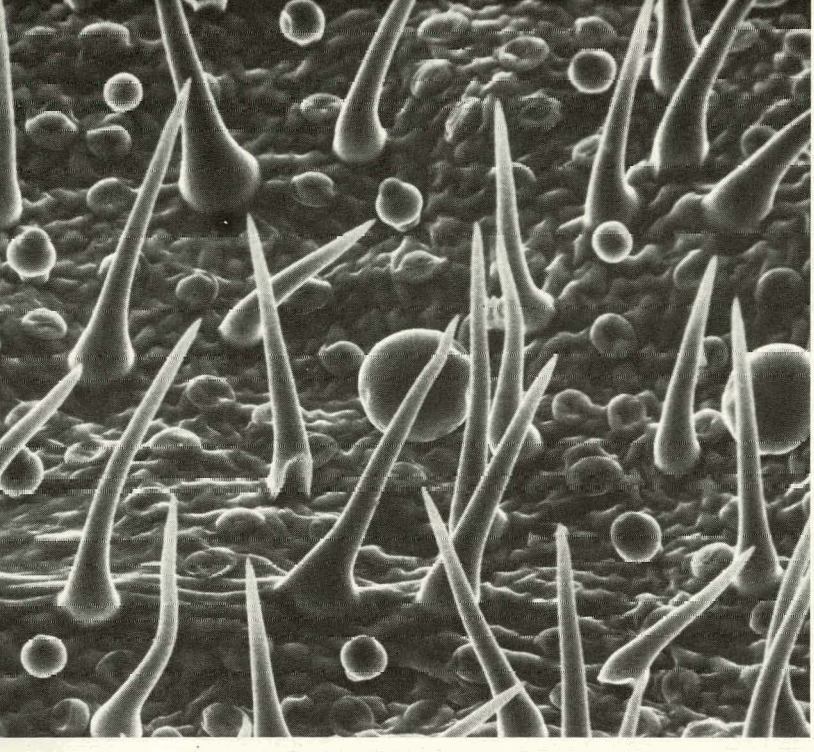


Figure 5. Scanning electron micrograph of abaxial (lower) leaf surface of marijuana examined fresh. One large sessile and several small stalked glands can be seen between the prominent smooth-surfaced conical hairs. 20 kV, 360×.

liquid nitrogen and observed in the frozen state. Micrographs of fresh and fresh-frozen plant samples are useful in many botanical studies and probably are the most faithful representations of plant surfaces yet available.

Plant Vacuoles

The mature cells of all higher plants contain a vacuole which occupies in excess of 90% of the total volume of the cell. The structure, function, and properties of this major cell component are essentially unknown because no method was available to isolate the vacuole from other cell components. Recently, a procedure was developed for isolating plant vacuoles. Plant tissues, such as leaves and flower petals, were sliced into narrow pieces and placed in a solution of enzymes which digested the cellulose cell walls releasing plant protoplasts. The protoplasts were treated with a solution of phosphate which gently burst the protoplasts and released the intact vacuoles. The vacuoles were then separated from other cell components, yielding a pure preparation of vacuoles. A comparison of the enzymatic activities in the vacuole and the cytoplasm revealed that most of the hydrolytic enzymes of the cell are localized in the cytoplasm.

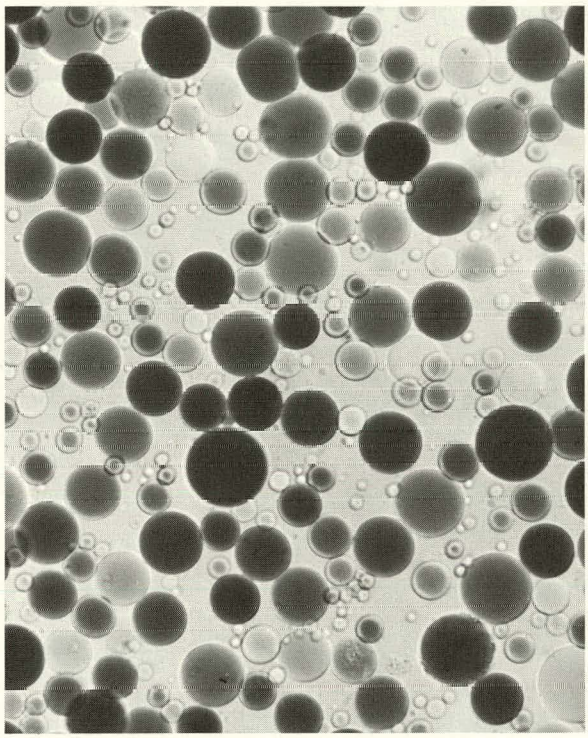


Figure 6. Intact vacuoles from flower petals from two *Tulipa* cultivars. Vacuoles were isolated by genetic osmotic rupture of enzymatically isolated protoplasts. Soluble anthocyanin pigments are contained in the sap of most vacuoles (about ×132).

PLANT GENETICS AND CELL BIOLOGY

Further understanding of DNA replication and mutation of gene expression in development, and of organic evolution are keystones to advances in plant genetics.

In order that each cell of an individual will receive a complete and accurate copy of the genes, the DNA molecule, in which the genetic information resides, must be reproduced in the chromosome without error. This is not a simple task for many reasons, not the least of which is the sheer size of the job to be done. Each cell nucleus in *Pisum sativum* (peas), for example contains more than 4 meters of DNA and in the dividing tissue of the root approximately 20 kilometers of DNA are replicated per hour. Techniques, developed at BNL, for analysis of plant cell DNA showed that the long molecule is replicated in many tandemly arranged units called replicons that number 4×10^4 in the *P. sativum* genome. Each replicon consists

Figure 7. Photomicrograph of an autoradiograph of isolated chromosomal DNA fibers. The spindle shaped "bubbles" result from separation of two newly formed duplex DNA fibers. The larger bubble is 92 μm and the smaller one is 70 μm long.

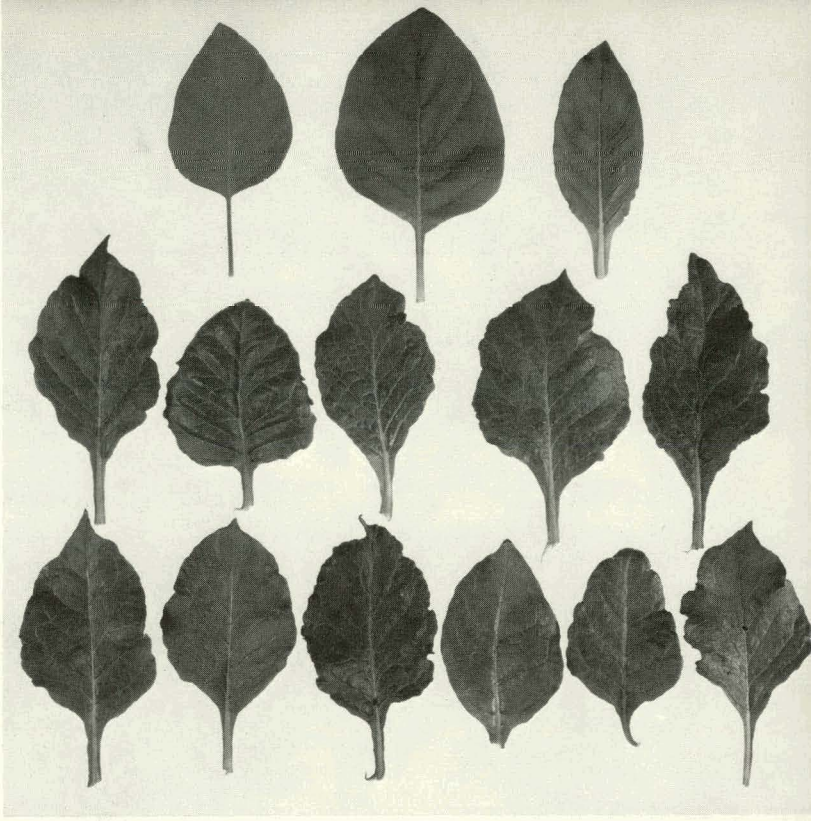


Figure 8. Leaves typical of (top row, left to right): *N. glauca, N. glauca* x *N. langsdorffii, N. langsdorffii*. Lower two rows show leaves characteristic of 11 different parasexual hybrids.

of two growing points that move concurrently in opposite directions along the parental DNA strands using the older DNA as a mold for the newly forming copies. Visualization of the replication process by autoradiography of radioactively-labeled DNA strands (Fig. 7) is a powerful tool for measuring the process and determining the mechanisms involved. It also aids in understanding how the chromosome, itself, is constructed.

Viewed in evolutionary terms it has now been shown that logarithmic distributions of the amount of DNA per haploid nucleus of species within major phylogenetic groups of organisms tend to form several peaks. These peaks appear to represent intragroup doublings of DNA or RNA which, in higher organisms, are independent of polyploidy. There are numerical similarities in peak values for different taxonomic groups. When minimum values for the major phylogenetic groups are plotted against a series of theoretical doublings, an exponential periodicity is observed over eight orders of magnitude. The periodicity suggests an evolutionary continuity of doublings of a basic ancestral genome (of about 300 nucleotides), which are independent of both chromosome number and ploidy level. The proposed continuity encompasses most major life forms and is concomitant with increasing evolutionary complexity, particularly in lower organisms.

The genes of nuclear DNA that are precisely replicated and increase in a step-wise fashion during evolution are commonly expressed and observed after segregation and recombination among like individuals via sexual mechanisms. These mechanisms may themselves constitute a barrier that precludes certain genetic combinations. New techniques indicate that these barriers can be circumvented by stripping plant cells of their walls and fusing the resultant protoplasts to form a parasexual hybrid. The only reported success of producing a mature interspecific plant hybrid by somatic cell fusion is that of *Nicotiana langsdorffii* x *N. glauca* performed at BNL. Because of the uniqueness and significance of this experiment, and in view of new advances in fusion techniques, the original work has recently been extended and verified. With the aid of polyethylene glycol as a

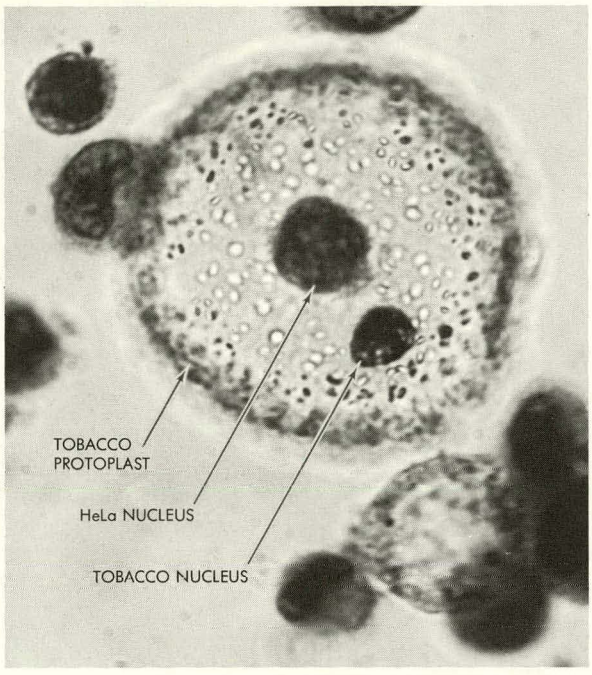


Figure 9. Heterokaryon with HeLa nucleus (the larger) outside a tobacco protoplast, 3 hours after fusion. A HeLa cell is also shown adhering to the protoplast membrane.

fusion agent, 174 hybrid cell colonies were recovered by growth on selected hormoneless culture medium. From these, 23 hybrid plants were grown to maturity. The parasexual hybrids were not simple additions of the two parental genomes ($2n=42$) but were higher chromosomc number aneuploids ($2n=56$ to 64). They were fertile and have produced progeny with unique recombinational characteristics (Fig. 8).

The potential range in combining widely disparate genotypes by somatic cell fusion was recently demonstrated by fusing tobacco tumor protoplasts with suspended human HeLa tumor cells in the presence of polyethylene glycol. The HeLa nucleus was observed inside the plant protoplasts (at about 0.2% frequency) within three hours of post-treatment incubation, thus forming a heteronucleate, interkingdom product (Fig. 9). The sequence from heterocellular adhesion to heterokaryon formation was followed by light microscopy and confirmed by autoradiography. The HeLa nucleus retained its integrity in the tobacco cytoplasm up to 6 days following fusion.

While nature through eons has evolved ways to assure genetic fidelity, mutations do occur – some spontaneously and others induced by physical and chemical means. Because many of man's activities require energy and because many of the products of energy production may be mutagenic, strong research efforts are being directed toward determination of the mechanism of mutagenesis at molecular and cellular levels, as well as the evaluation of suspected mutagens themselves. For example, methods developed for studying the effects of physical mutagens utilizing a *Tradescantia* genetic test system can be applied with very little modification to chemical mutagen investigations. Also, dose-response results from physical mutagen treatments can be used for baseline comparisons with data from chemical mutagen experiments. Present observations indicate that the system is sensitive enough to detect a significant increase in mutation frequencies at levels well below 1 part per million for some gaseous mutagens. Greater efficiency of the test system is being sought, through basic genetic studies and a breeding program aimed at obtaining more sensitive clones, devising more effective chemical mutagen exposure methods, and improving dosimetry.

REACTIVITY OF DNA IN CELLS – RECOMBINATION AND REPAIR

After DNA is synthesized, it can be methylated, cleaved by various enzymes and recombined into new forms. DNA is susceptible to damage by external agents, but the cell has systems to repair such damage. Unrepaired damage to DNA is probably responsible for environmentally caused cancer. If a cell is unable to remove the damage by excision repair (in which damaged residues are enzymatically removed and replaced by new, undamaged ones), the synthesis of new DNA from the damaged DNA may give rise to an erroneous copy of the original template and a mutation results. In bacteria radiation also enhances the very process of making mistakes, which are associated with part of the postreplication repair. Such ultraviolet-induced mutations are also associated with the appearance of an ultraviolet-induced protein, which is not formed in bacterial strains that are not mutable by ultraviolet radiation.

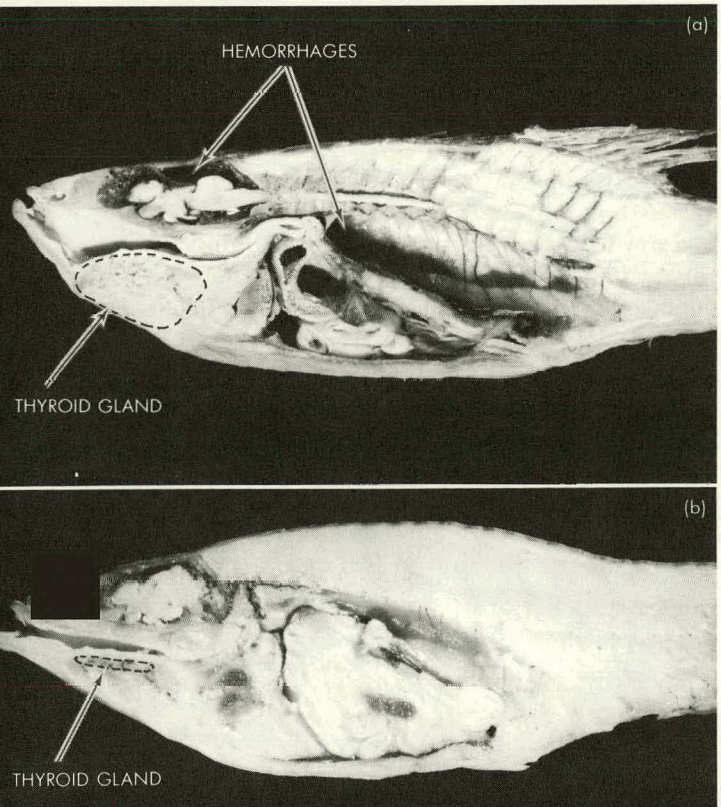
People with the inherited disease xeroderma pigmentosum are very susceptible to sunlight-induced skin cancer. Most of these individuals are defective in excision repair, and some are defective in postreplication repair. The latter group is similar to mutable bacteria in that radiation en-

hances a part of the postreplication repair system – presumably the error-prone part. These findings are support for the hypothesis that errors made in the replication of DNA on damaged templates give rise to neoplastic transformation.

A human placental enzyme has been isolated which preferentially removes ultraviolet-induced pyrimidine dimers from DNA that has been previously nicked with a dimer-specific endonuclease from bacteria. The exonuclease can degrade DNA in either direction, starting at any incision. Thus the enzyme can remove any damage next to an incision made by a specific endonuclease. Cells from three xeroderma pigmentosum patients have been found to contain normal levels of this exonuclease activity. Thus defective incision is probably more commonly the basis for excision defects associated with this disease.

A novel biological test system has been developed to assess quantitatively the carcinogenic potentials of hazardous physical and chemical agents in the environment. A species of tropical fish, *Poecilia formosa*, reproduces in such a way that the offspring are identical females. Hence cells removed from one animal are not rejected when transplanted to another. Cells may be treated in the test tube, where the dosage of chemicals or radiation is readily controlled. The cells' abilities to form tumors are determined by injecting them into identical sisters and observing whether the recipients develop tumors. Figure 10 (a) shows a section of a fish injected with cells exposed to 500 rads of gamma rays, and Fig. 10 (b) a section of a fish injected with untreated cells. The former has an invasive thyroid tumor, and as indicated by its reddish color (not seen in the figure) an abberant hematopoietic system.

Figure 10. (a) A section from a fish injected with fish cells exposed to 500 rads of gamma rays. There is an invasive thyroid tumor, and as indicated by its reddish color (not seen in this figure), an aberrant hematopoietic system. (b) A section of a fish injected with untreated cells.



During post-replication repair in the bacterium *Haemophilus influenzae* extensive exchanges occur between parental DNA and the DNA made after irradiation, except in a recombination-defective strain which is unable to fill in gaps in strands of DNA synthesized on ultraviolet-damaged templates. Thus sister-strand recombination is important for gap filling in this microorganism. Gap filling takes place at the restrictive temperature in a mutant that is temperature sensitive for DNA synthesis. Thus gap filling does not require normal semiconservative DNA synthesis.

An ATP-dependent deoxyribonuclease in *H. influenzae* may be part of one of the pathways in recombination. Investigations of the genetics, complementation and sensitivity to various agents among eight mutants defective in this enzyme have shown that there are three complementation groups corresponding to three different cistrons in the genome, which apparently code for the enzyme known to have three different subunits. The ATP-ase associated with the enzyme is present only in the mutants which are least sensitive to a variety of chemical agents, suggesting that ATP-ase deficiency in the mutants is associated with increased cell permeability.

Pneumococcal bacteria can be genetically transformed by DNA taken up from outside the cells. Analysis of this process showed that double-stranded donor DNA is first bound at the cell surface. This binding involves single-strand breaks in the DNA that may enable it to attach to surface receptors. Subsequently, single strands of donor DNA, which contain the genetic information, are introduced into the cell. At the same time, an equivalent amount of donor DNA is broken down to small pieces outside the cell. Both DNA entry and breakdown are mediated by a deoxyribonuclease that is located in the surface membrane of the cell. This enzyme presumably attaches to , and degrades, one strand of DNA in sequential fashion, thereby drawing the other strand of DNA into the cell.

Restriction endonucleases are enzymes that cut DNA only at specific base sequences. All those that have been heretofore found are blocked by methylation of a base in this sequence. A restriction endonuclease isolated from a strain of pneumococcus, on the contrary, was found to require methylation of a specific sequence for its action. Another pneumococcal strain produces a restriction endonuclease that acts at the very same base sequence, but only when it is not methylated.

MOLECULAR GENETICS

Viruses are small infectious agents that require living cells for their replication. A common feature of all viral infections is the ability of the virus to convert the metabolism of the host cell to the production of new virus particles. Studying the interactions of viruses with their hosts provides information concerning the mechanisms of genetic expression in a wide variety of organisms.

The simplest hosts for viruses are bacterial cells. In this laboratory the bacterial virus T7, which infects *Escherichia coli*, has been used as a model system for learning how viruses interact with their hosts. When T7 comes in contact with an *E. coli* cell, its DNA is injected into the bacterium and viral mRNAs begin to be made. The leftmost 20% of T7 DNA is referred to as the early region because the mRNAs specified by this part of the DNAs are the first to be made after infection. RNA from the early region is synthesized by the host RNA polymerase and is cut at five sites by a second host enzyme, RNase III.

Cutting of the early RNA by RNase III produces six individual RNAs five of which then function as messengers for protein synthesis. When a mutant of *E. coli* that lacks RNase III is infected with T7, the early RNA remains uncut. In this host, four of the five early proteins are made normally but the fifth is made only in small amounts. Apparently, cutting of the messenger RNA is needed for efficient synthesis of at least one early protein.

RNase III is very specific, since it cuts the early T7 RNA at only five places, in a stretch of RNA about 8000 bases long. In an effort to learn the basis for this specificity, the enzyme has been purified and its interaction with RNA analyzed. The sequence of bases around each cleavage site is being determined in order to find out what features of the RNA are recognized by this enzyme.

It has been known for some time that bacteria such as *E. coli* have a defense mechanism that destroys foreign DNA. Yet, T7 DNA can enter *E. coli* and direct the synthesis of new viruses in spite of this defense mechanism. Recently it was found that the first T7 protein made after infection acts specifically to counteract the defense of *E. coli*, probably by inactivating an enzyme that would normally break up foreign DNA. T7 mutants that lack this protein are unable to grow on *E. coli* because their DNA is destroyed.

T7 DNA contains the information for making all of the T7 proteins, and also contains many signals that are recognized by enzymes involved in making messenger RNAs or in replicating the T7 DNA. Such signals are being mapped on the DNA by cutting the DNA with enzymes called restriction endonucleases. These enzymes cut the DNA at specific sites, and specific pieces of DNA are produced. The DNA fragments are separated from each other by gel electrophoresis. Such pieces of DNA are being isolated so that the location and base sequence of specific recognition signals can be determined. In this way it should be possible to understand in further detail how genetic information is expressed in the cell and how DNA is made.

PHOTOSYNTHESIS

The first events in photosynthesis are the trapping of photons by light-harvesting pigments, which subsequently transfer their excitation to photochemical reaction centers for conversion to chemical free energy. Many light-harvesting pigments exist inside living cells as pigment-protein complexes. In blue-green and red algae bile pigments in protein complexes serve as the main collectors of solar energy. These pigments have been isolated from algal extracts by high resolution chromatography and characterized by mass spectroscopy. The discovery of the methanol adduct of phycocyanobilin (a blue pigment) furthers our understanding of the nature of pigment binding in biliproteins.

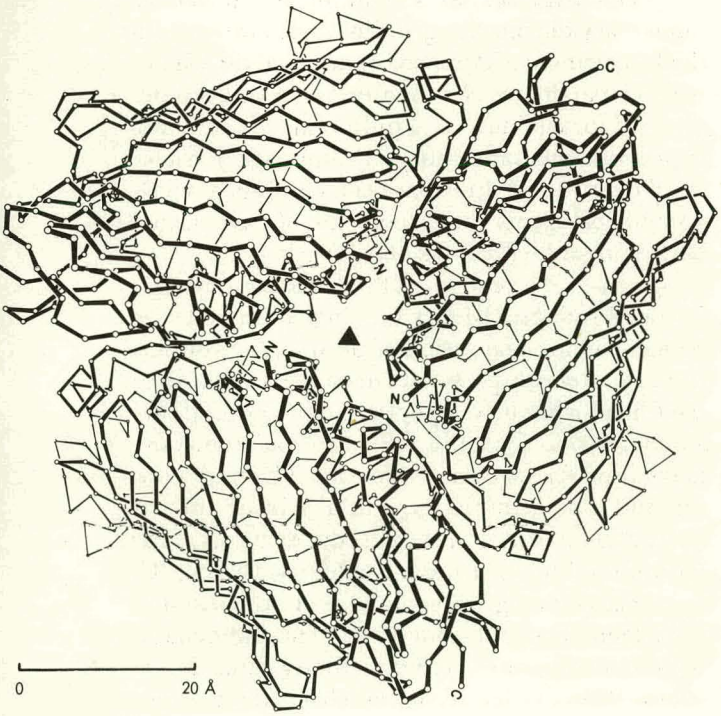
In the dinoflagellate alga *Amphidinium carterae* the main light-harvesting pigment-protein is a water-soluble complex (mol. wt. = 39,000) containing nine carotenoid (peridinin) molecules and two chlorophyll *a* molecules. Of similar size is the subunit (mol. wt. = 44,000) of a bacteriochlorophyll *a*-protein which transfers excitation from

light-harvesting chlorobium chlorophyll to reaction centers in green bacteria. Each of the three subunits contains seven bacteriochlorophyll *a* molecules completely surrounded by a polypeptide chain of at least 327 amino acid residues. The average center-to-center distance between chlorophyll nearest neighbors is 12 Å. Each chlorophyll is held in place by the protein.

The bacteriochlorophyll α-protein is associated with reaction center activity in intact green bacteria and in an isolated membranous complex (mol. wt. >1.5 million). Light energy absorbed by the chlorophyll in the protein is transferred to the reaction center to drive the transfer of an electron from bacteriochlorophyll *a* ($E = +0.25V$) to an acceptor ($E = -0.54V$). The free energy stored in this photochemical reaction is ~ 0.8 eV, for an energy conversion efficiency of $\sim 50\%$.

Energizing of a photosynthetic reaction center leads to the separation of charge across the membrane in which the reaction center is embedded. The low potential electron so derived is used in two ways: as a reductant in the CO_2-fixation process and as a source of chemiosmotic potential. Chemiosmotic potential is expressed as some combination of membrane potential and trans-membrane pH gradient, the latter being dominant in the inner chloroplast membranes of higher plants. The movement of protons which sets up the pH gradient must be accompanied by fluxes of other ions to maintain electroneutrality. By means of an apparatus embodying a range of ion-specific electrodes, simultaneous observations of all these ion fluxes have been made. The light-driven reversible proton uptake is accompanied both by reversible Cl^- uptake and Mg^{2+} extrusion, with very little movement of Na^+ or K^+. It follows that *in vivo* the Mg^{2+} content of the chloroplast stroma rises in the light and falls in darkness. Calculations indicate an effective change in stroma Mg^{2+} concentration over the range which governs the activity of three principal enzymes of the carbon fixation pathway; thus light-driven proton pumping indirectly activates the machinery needed to utilize the chemiosmotic potential and the low potential electrons.

Figure 11. Bacteriochlorophyll *a*-protein from the green photosynthetic bacterium *Chlorobium limicola* 2K. Each of the three subunits contains seven chlorophyll molecules (not shown) inside the polypeptide outer shell. The small circles represent alpha carbon atoms of amino acid residues. (Figure courtesy of R.E. Fenna and B.W. Matthews, University of Oregon.)



The pathways through which electrons are driven, by two serial photochemical reactions, to the terminal low potential reductant in blue-green algae and chloroplasts are not well understood. Primarily responsible is the complexity of light-induced changes in absorbance throughout the visible spectrum, which make special spectrophotometric techniques necessary for discernment of pigment function and electron transport sequence. To attack this problem, a new type of scanning differential spectrophotometer has been constructed having high differential absorbance sensitivity, yet, by virtue of its computer link, it is able to cover scan ranges with widely varying absolute absorbance. The computer is also used to resolve the spectral envelopes on the basis of components known to be present in the chloroplast. Photostationary states analyzed in this fashion, with support from kinetic measurements, have revealed details of the function of cytochromes b_6, b-559, and f in the chloroplast.

PHOTOPERIODISM

Many processes, and particularly reproduction, in both plants and animals are environmentally

controlled through photoperiodism, a response to the timing of light and darkness. In plants, photoperiodism involves both endogenous circadian rhythmicity – the so-called biological clock – and a light-absorbing protein, phytochrome, but the nature of their interactions is unknown. In a new approach, the patterns of carbon dioxide output by photoperiodic plants under sterile conditions have been studied on schedules combining light of different wavelengths with various periods of darkness. Interactions analogous to those found in photoperiodism can be identified in such patterns. Furthermore, these interactions can be modified by compounds affecting amino acid metabolism.

The significance of these results for understanding photoperiodism is twofold. First, the indicator of photoperiodic timing obtained is metabolic rather than a change in growth or morphology, and, as such, more susceptible to analysis. It is the first such indicator reported by any laboratory. Secondly, the ability of a change in the nitrogen source to modify or abolish the pattern should prove invaluable in identifying the source of the CO_2 involved, and thus a reaction or reactions controlled by the photoperiodic timing mechanism.

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MEDICAL DEPARTMENT

INTRODUCTION

The Medical Department, dedicated to the betterment of man's health, is now entering a new period of emphasis on the effects of environmental pollutants related to energy production. Many scientific programs are shifting in direction and new efforts are being made to initiate both clinical and basic researches which have application to either specific energy production processes or are multitechnological in nature. Collaboration with the neighboring academic and health-care institutions as well as other scientific departments at Brookhaven is encouraged and leads to productive research which would otherwise be slow to develop or impossible to attain.

Areas of scientific pursuit range from studies of the cellular function of unusual biochemicals to development of new radiopharmaceuticals which aid in the diagnosis of human disease. Related to the projects under way on the effects of radiation on human cells and tissues are new programs examining the biological effects of other phases of our environment. The unusual organization of the Laboratory and the Medical Department under Associated Universities, Inc. and the Energy Research and Development Administration provides the latitude necessary for development of a project in both breadth and depth, as progress dictates. Furthermore, this organization enables the Department to respond to both immediate scientific goals and national needs.

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.

NUCLEAR MEDICINE

Development of Diagnostic Imaging Techniques

Special emphasis has been in the area of cardiopulmonary diagnostic agents in collaboration with the Department of Applied Science and the Chemistry Department. New materials have been developed for evaluation of pulmonary function in support of the Laboratory's Pulmonary Toxicology Program and there has been continued development of agents for assessment of myocardial perfusion and left ventricular function.

Xenon-127, a product of the Brookhaven Linac Isotope Producer (BLIP), is being compared with xenon-133 for evaluation of pulmonary ventilation. Its superior physical characteristics of long shelf-life, higher flux of photons, more appropriate gamma rays for imaging, and lower radiation dose make it preferred over xenon-133. The high photon flux permits rapid sequential scintigraphy of ventilation in order to study redistribution of gas within the lungs during a single breath (Fig. 1).

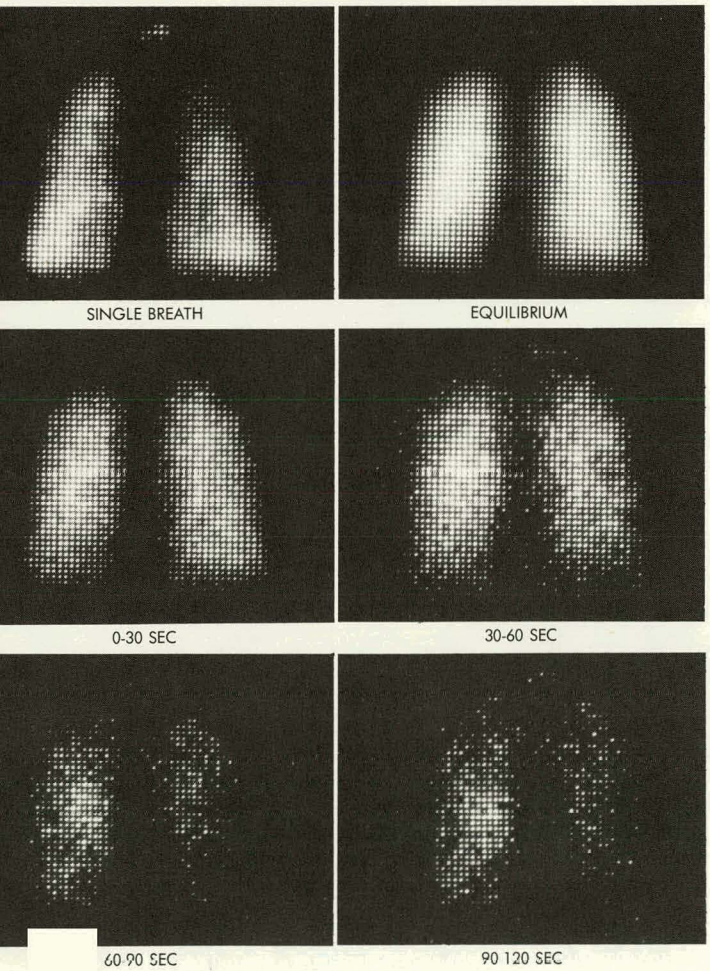
A study of long term whole body retention of radioxenon has been completed. This has demonstrated a component of whole body retention of about 10 hours half-time which correlates very

closely with percent body fat and which is of some importance in dosage calculations (Fig. 2).

A compound, ^{11}C-octylamine, has been developed to evaluate monoamine oxidase activity in the lungs. This compound is one of a class of compounds that has specific affinity for the lungs. Studies in animals are being performed to evaluate the effects of monoamine oxidase inhibitors on lung washout of ^{11}C-octylamine and related substances. Clinical evaluation has also been initiated.

There has been continued study of the distribution of thallium-201 in the body. Clinical studies have been performed utilizing gated images, thus demonstrating wall motion.

Figure 1. Ventilation study performed with ^{127}Xe. Images were obtained sequentially during the study and show initial distribution of radioactivity in the lungs after a single breath, following rebreathing through a spirometer (equilibrium), and at intervals during washout. The lungs are viewed from the rear. There is slow disappearance of radioactivity from the mid-left lung.



The ^{99m}Tc-red blood cell labeling kit is undergoing clinical evaluation. It is proving useful in assessing patency of major vascular structures as well as in determining the kinetics of left ventricular wall motion. Studies with animals are being performed to evaluate the feasibility of regional hematocrit determination.

Treated red cells are being used to image the spleen. Uptake studies are being performed to assess splenic function with varying amounts of such labeled cells administered intravenously.

OXIDATIVE AND FREE RADICAL MECHANISMS UNDERLYING THE ACTIONS OF POLLUTANTS

The biomedical damage caused by oxidizing pollutants, such as ozone and nitrogen oxides, often results from free radical-mediated oxidation reactions in tissues. Many organic pollutants that have the potential to cause cancers or mutations require metabolic activation by cell enzyme systems. These enzymes also detoxify the same com-

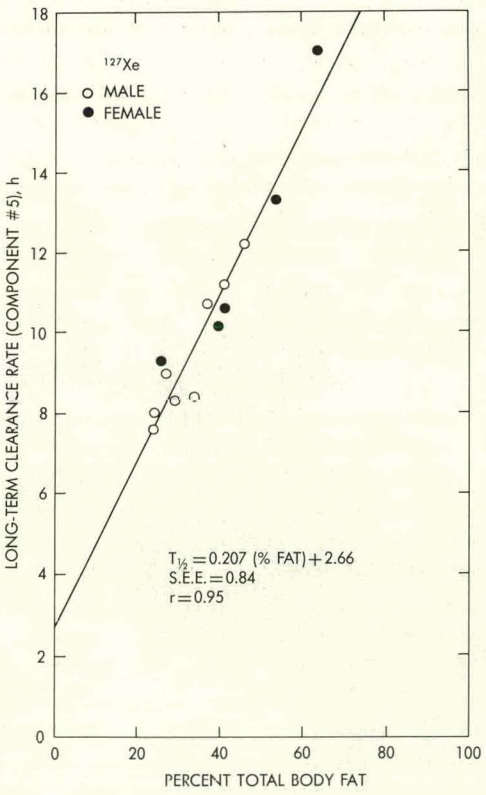


Figure 2. Correlation of long-term clearance rate of ^{127}Xe ($T_{1/2}$ in hours) with per cent body fat in 13 subjects.

pounds, and some steps in their reaction pathways involve free radicals. Furthermore, there is evidence that certain of these chemicals trigger their effects by combining through their free radical forms with biological target molecules, especially DNA.

Since free radicals are odd-electron chemical species that are usually highly reactive and therefore short-lived, their concentrations in tissues and in biochemical reactions tend to be very low. The need to detect relatively small numbers of free radicals in biomedical experimentation has led to the widespread use of electron paramagnetic resonance (EPR) spectrometry, because EPR and related magnetic resonance techniques can identify and describe free radicals with the greatest sensitivity and specificity.

The effects of attack upon the component bases and nucleosides of DNA by OH radical, one of the most reactive intermediates in oxidative damage reactions, have been investigated with a fast-flow mixing system which allows the short-lived radical species formed from the DNA bases to be studied and identified by EPR. Recent work identified the products of the reactions of purine bases and nucleosides with OH radicals, and various purine base radicals (mostly adducts on ring nitrogen atoms or on carbon-5, plus sugar radicals in nucleosides) were observed and identified from the EPR data in conjunction with isotopic substitution, molecular orbital calculations, and computer simulations.

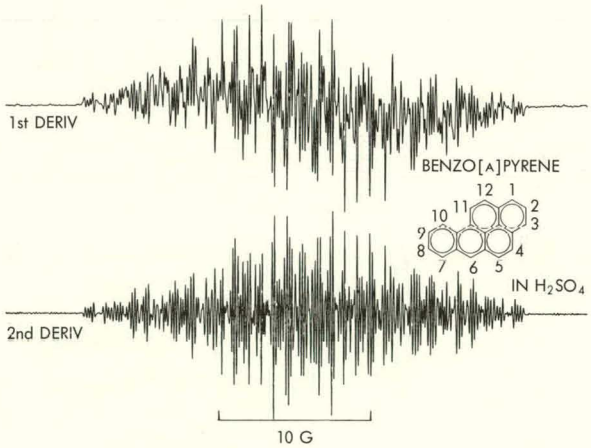


Figure 3. EPR spectra from the cation free radical of benzo(a)pyrene. This particular free radical form has been studied before, but the detailed resolution of this spectrum is new. Other data suggest that the radical from 6-hydroxybenzo(a)pyrene may be a more likely product of metabolic activation than is this form.

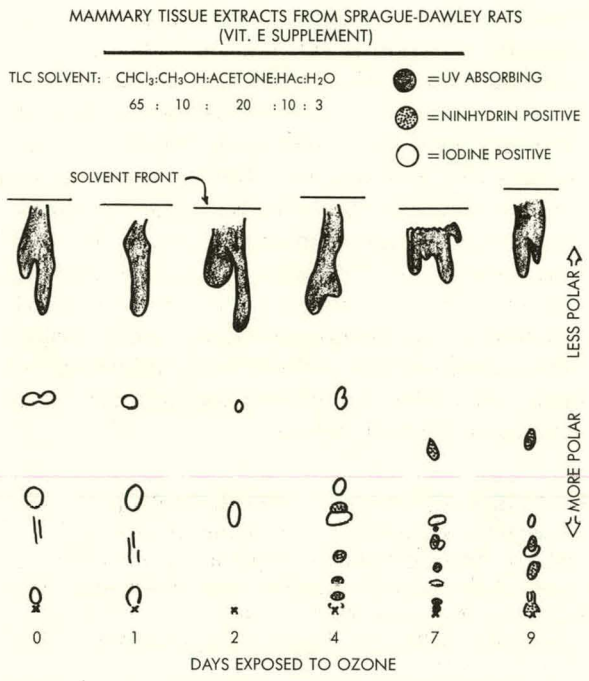


Figure 4. Thin-layer chromatogram of lipid extracts from mammary tissues of female Sprague-Dawley rats exposed to 2 ppm of ozone for 5 hours on successive days. In the solvent system used (chloroform, 65 parts; methanol, 10; acetone, 20; acetic acid, 10; water, 3), less polar products migrate faster (i.e., in the upward direction toward the solvent front). After about 4 days of exposure, new relatively polar products are seen to appear, and some normal products disappear. This indicates biochemical changes in the breast fat following respiratory ozone exposure.

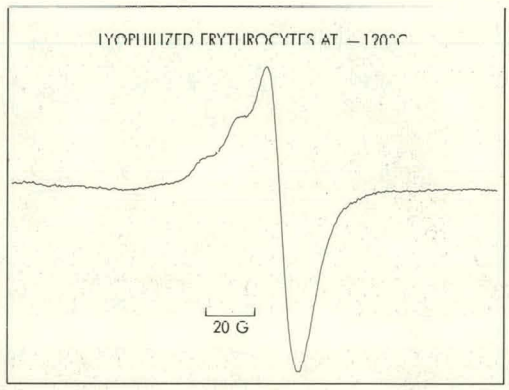


Figure 5. EPR spectrum from freeze-dried human red blood cells examined at low temperature. The two spectral shoulders on the low-field (left) side represent sulfur-centered free radicals, while the larger biphasic peak includes the carbon-centered ones. Similar spectra are observed in other tissues, and in model chemical systems containing unsaturated fats and proteins, upon exposure to various oxidizing stresses such as ozone, oxidized lipids, etc.

EPR studies on free radicals obtained from known cancer-causing chemicals [benzo(a)pyrene, 7,12-dimethylbenzanthracene, and 3-methylcholanthrene], assisted by computer data accumulation and processing methods, revealed new spectral detail. Although the EPR spectra were obtained under nonphysiological conditions, further identification of the various important free radical forms of these compounds is now possible (see Fig. 3).

Ozone is a natural constituent of air, but it is also an energy-related air pollutant, being the most toxic oxidizing component of photochemical smogs. Although pulmonary effects from ozone have been known for some time, recent findings that ozone exposure of animals can damage chromosomes has raised the question of possible cancer-causing potential from ozone exposure. An experiment is under way to test this question on a well established mammary tumor test system in female Sprague-Dawley rats. Supporting studies of extrapulmonary cell damage mediated by ozone attack on membrane lipids and proteins are carried out by this program. Positive manifestations of tissue damage beyond the lung have been obtained from the inactivation of enzymes on the surfaces of red blood cells and from chromatographic and characteristic fluorescent changes in the extracted lipids of the blood cells. Changes in the lipids of breast tissue were also seen to accumulate upon repeated exposures of rats to ozone (see Fig. 4), suggesting that biochemical stress had occurred in the target tissue of the cancer study.

Comparison of the EPR spectra of freeze-dried blood with known radical products from ionizing irradiation has identified multiple free radical components in the blood, including carbon-centered and sulfur centered ones (see Fig. 5). The sulfur radicals are relatively stable and nonreactive and can inhibit damaging reactions by scavenging more reactive free radicals or by reconstituting hydrogen-abstraction or OH-addition sites on biomacromolecules. It may be possible to monitor the sulfur radical changes to follow tissue damage from ozone and other pollutants.

Porphyrin and Chlorophyll Studies

Porphyrins and their oxidation and reduction products have been studied in order to better understand the mechanism of action of enzymes in which a porphyrin entitity is the active center, such as the many cytochrome enzymes involved in basic metabolic oxidation reactions of cells. As shown by EPR, porphyrin radicals are produced on oxidation or upon reduction. The cation radicals have been found to fall into two classes with characteristic EPR and optical spectra. Certain intermediates in the reactions of the enzymes catalase and peroxidase in their decomposition of peroxides have been found to be very similar in their properties to each of these states, the catalase compound corresponding to one of the states and the peroxidase one to the other.

Chlorophylls are closely related to porphyrins, and in conjunction with work in the Department of Applied Science, similar studies have been carried out on cation and anion radicals of chlorophylls and related compounds. The molecules which are involved in the photochemical steps in photosynthesis are studied in the belief that knowledge of natural photosynthesis may guide solar energy production of electricity or hydrogen from water. The work utilizes electrochemistry, optical spectroscopy, computer-assisted EPR, and electron-nuclear double resonance (ENDOR). The optical, EPR, and ENDOR properties of the anion free radical of magnesium-free bacteriochlorophyll (bacteriopheophytin) were elicited and compared to data from laser flash photolysis recently obtained from other laboratories. On this basis, the bacteriopheophytin anion was tentatively identified for the first time as the primary electron acceptor in bacterial photosynthesis. The bacteriochlorophyll free radical cation, the electron-donor product of the first photochemical step of bacterial photosynthesis, was previously described in this laboratory, using EPR and ENDOR methods.

EFFECTS OF RADIATION

Radiological Research Accelerator Facility

The Radiological Research Accelerator Facility (RARAF) is a joint enterprise of Brookhaven's Medical Research Center and the Radiological Research Laboratories of Columbia University. The Brookhaven Biology Department and the Department of Applied Science are also involved, as are investigators from other universities from time to time.

The facility utilizes a 4-MV Van de Graaff accelerator, which had earlier served as the injector for the BNL Cosmotron, to produce charged particle beams and monoenergetic neutrons of from

about 0.1 to 15 MeV. The radiations are used for basic and applied investigations of radiation effects on living systems. Radiobiological projects include experiments on mutation, chromosome aberrations, cell killing, and cancer induction, and utilize a wide variety of experimental organisms, including plants, insects, mammals, and single cells growing in tissue culture. During the past two years experiments of two new types were begun; in one, the killing of Chinese hamster tissue culture cells by very closely spaced pairs of charged particles is being investigated; the other measures chromosomal aberration production, killing, and nucleic acid strand breakage by protons, deuterons, and helium ions in order to determine the influence of the rate at which the radiation's energy is deposited. More applied experiments designed to improve radiation therapy of human cancers study the killing of cells by various particles and the influence of oxygen tension during exposure.

Comparison studies in radiological physics include precise determination of physical quantities needed to improve dose measurement and measurements of energy deposition in microscopic volumes which are utilized in the development of theoretical biophysical models of radiobiological processes.

A new project undertaken recently is to construct a proton microbeam facility which will enable investigators to hit particular locations within living cells with single protons with an accuracy of plus or minus one micrometer. When completed, the facility will provide a unique tool for probing the cell nucleus at the microscopic level.

Radiation Carcinogenesis of the Rat Mammary Gland

Many women have their breast tissues exposed to x-irradiation and many women receive estrogenic (female) hormones. There is some question as to whether or not women who receive both of these agents might be at high risk for the development of breast cancer. The scientific literature contains one report wherein an experimental model system was set up to test the interaction of x-rays and female hormones on the induction of breast tumors with the findings that the combined treatment of x-irradiation and diethylstilbestrol (diethylstilbestrol is a synthetic estrogenic substance thought capable of producing all the pharmacologic and therapeutic responses attributed to

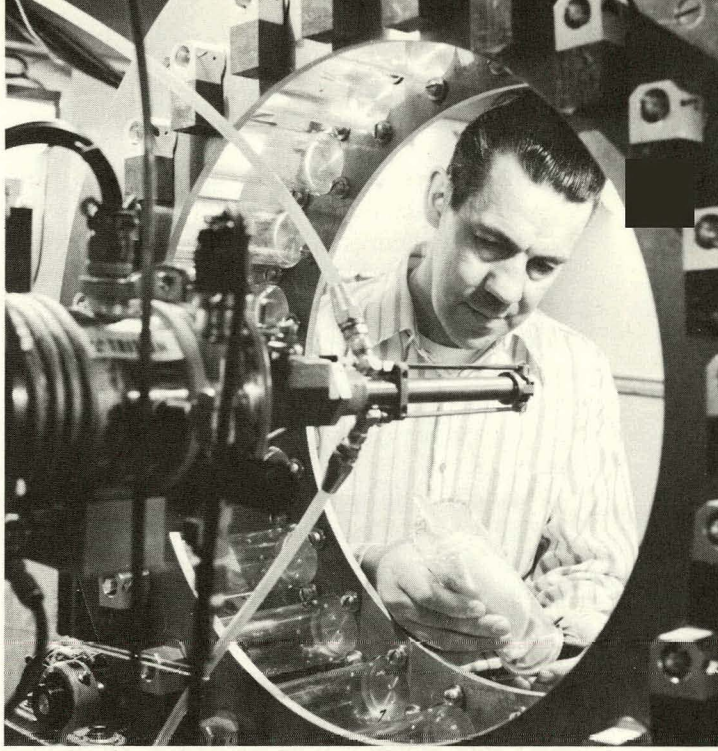
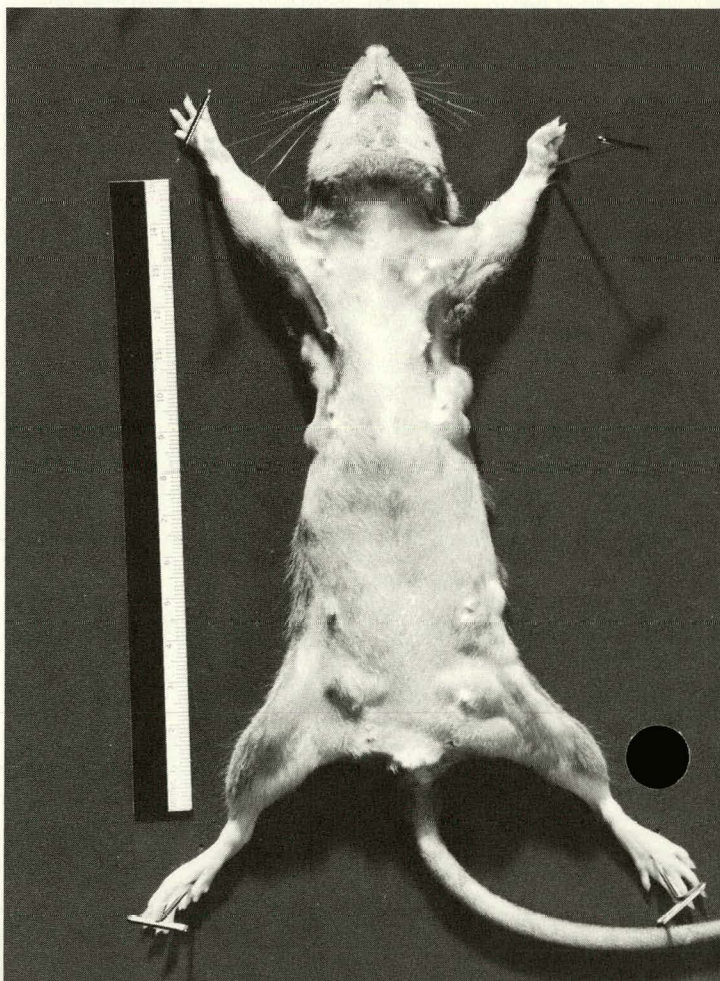


Figure 6. Rats are loaded into special rotating cages prior to being irradiated with monoenergetic neutrons for studies of the induction of mammary gland cancers.

Figure 7. Female A X C rat that received a 5mg compressed pellet of diethylstilbestrol two days before 9.6 rads of 0.43 MeV neutron radiation, 30 weeks before this picture was taken. All of the many lumps that can be seen proved to be breast tumors (mammary adenocarcinomas) upon microscopic study.



natural estrogens) resulted in more breast tumors appearing than with either agent given alone. Because an increasing number of women are likely to be exposed to neutron radiation as neutron radiation is used increasingly in clinical medicine, it seemed prudent to learn if neutron radiation would also interact with estrogen. Accordingly, A X C female rats were given either diethylstilbestrol, or 9.6 rads of 0.43 MeV neutrons (produced and measured at RARAF), or both agents. Fifty weeks later, 22 of 25 rats given diethylstilbestrol developed a total of 182 breast tumors, two of 33 rats given neutron radiation only developed a total of two breast tumors, and 32 of 35 given both diethylstilbestrol and neutron radiation developed a total of 842 breast tumors (see Fig. 7). Clearly, in this experiment, with this model system, estrogen and neutron radiation acted together to produce many more breast tumors than the sum of the number of breast tumors produced by either agent alone. Current studies are directed toward the understanding of the hormonal mechanism of this interaction of neutron radiation and estrogen in order to determine just how closely results from this animal model system might apply to the human situation.

CHRONIC LYMPHOCYTIC LEUKEMIA

Clinical Staging and Therapy With Extracorporeal Irradiation of Blood

Lymphocytes play a major role in etiopathogenesis of many human diseases including chronic lymphocytic leukemia (CLL). CLL is characterized by progressive accumulation of functionally incompetent and neoplastic lymphocytes and the disease runs a variable course. The increase in the body burden of leukemic lymphocytes is accompanied by malfunctioning of the immune system leading to frequent infections and abnormal bone marrow function. The current treatment of CLL, essentially drugs, causes inescapable, non-discriminatory effects on an already depressed immunohemopoietic system, therefore, it is necessary to explore alternative approaches with less damaging effects on hemopoiesis.

In order to provide reliable parameters for clinical assessment of CLL patients, a method of clinical staging has been developed. This system, which is based on the number of blood and/or marrow lymphocytes, degree of lymph node, spleen, and liver enlargement, and the severity of anemia and thrombocytopenia, divides CLL into

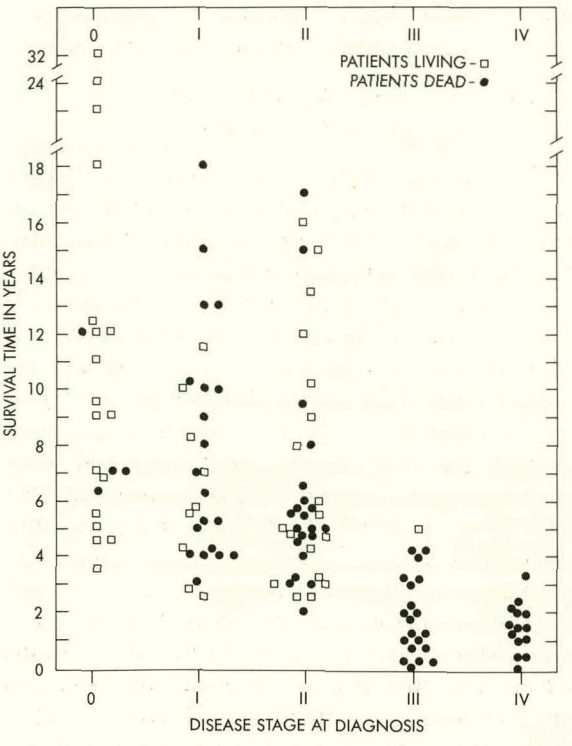


Figure 8. Survival time by stage for chronic lymphocytic leukemia patients.

5 stages. Median survival (in months) of 125 patients from diagnosis was as follows: stage 0, >150; stage I, 101; stage II, 71; stage III, 19; and stage IV, 19 (Fig. 8). This method of staging proved to be a reliable predictor of survival whether used at diagnosis or during course of the disease.

The role of extracorporeal irradiation of blood (ECIB) as a possible adjunct to conventional therapy continues to be evaluated. ECIB induces no direct injury to hemopoietic tissues other than the circulating cells and exploits the relative radiosensitivity of lymphocytes as compared to other blood elements. By virtue of the unique traffic patterns of lymphocytes between blood and tissues, ECIB induces depletion of lymphocytes not only from blood but also from lymphoid organs. Figure 9 shows the depletion of blood lymphocytes in a CLL patient. A short course of Prednisone therapy, instituted at a time when there was no further response to ECIB, resulted in additional blood lymphocyte reduction. The median duration of survival of 28 patients (stages III and IV) at Brookhaven who received conventional therapy only was 1.5 years. Six patients (stages III and IV) who received ECIB in addition to conventional

therapy had a median survival of 2.6 years. These results, despite the small numbers, are encouraging.

Measurement of Total Tumor Burden and Quantitation of T-Lymphocytes

The information derived from our newly proposed clinical staging of chronic lymphocytic leukemia (CLL) has confirmed the concept that CLL is a disease characterized by progressively increasing accumulation of abnormal lymphocytes. We are attempting to independently confirm the correlation of total body lymphocyte mass and the clinical stage of the disease. For this purpose total body potassium (TBK) measurement has been employed to estimate the total body cell mass, since more than 95% of TBK is found within the cells. Since nearly 0.012% of natural potassium consists of a radioactive isotope (^{40}K) which emits gamma rays, this naturally occurring isotope can be measured *in vivo* with the Whole Body Counter of the Medical Department. Preliminary results are encouraging as patients with early stages (0 and I) show minimal increment of TBK while patients with more advanced disease (stages II and III) have significantly elevated TBK.

Due to significant impairment of the immune functions in CLL patients, our clinical research protocols include periodic evaluation of the immune status of these patients. Recently, a two-component concept of the immune system has emerged implicating two main populations, the bone-marrow derived, thymus independent cells (B cells), and the bone-marrow derived, thymus dependent cells (T cells). In most cases of CLL, B cells constitute the majority of abnormal lymphocytes. Human T cells are commonly identified as the cells which form rosettes with sheep red blood cells (E-rosettes) when incubated under appropriate conditions. The currently used methods for enumeration of E-rosettes are not very satisfactory. We have recently developed a new technique for the permanent preparation of E-rosettes which is semi-automatic, thus eliminating individual variations. The E-rosette smears can be stained and the identification of the rosette-forming cell can be carried out with ease and with a great degree of precision. The figure shows one of these fixed preparations.

Thymocyte Migration

It is well known that the thymus plays an important role in the development of peripheral lymphoid tissues and immunologic responsiveness, particularly of the so-called cell-mediated immunity. This role is assumed to be accomplished principally by production within the thymus of immunocompetent lymphocytes which subsequently leave the thymus and migrate to peripheral lymphoid tissues, where they contact antigen.

Although death of thymic lymphocytes *in situ* occurs, it has been shown that a large fraction of newly produced thymic lymphocytes emigrates.

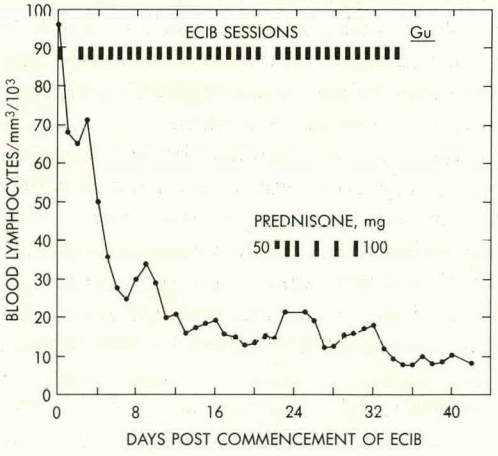


Figure 9. The depletion of blood lymphocytes in patient *Gu* with chronic lymphocytic leukemia. A short course of Prednisone therapy, instituted at a time when there was no further apparent response to extracorporeal irradiation of blood (ECIB), resulted in additional depletion.

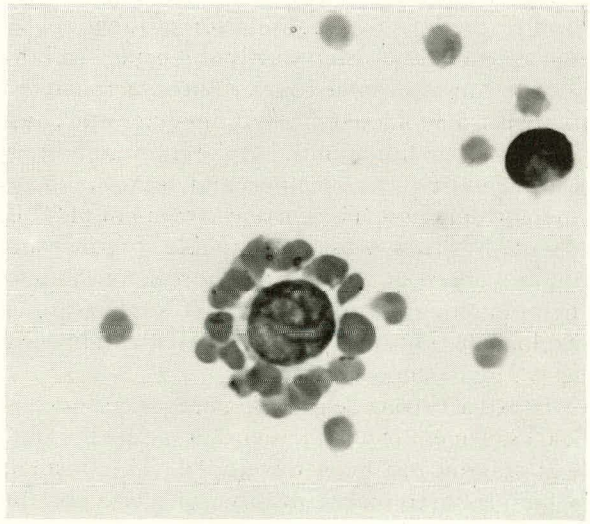


Figure 10. Micrograph showing an E-rosette with central lymphocyte and surrounding sheep red blood cells.

Factors controlling peripheral migratory patterns of thymic lymphocytes and the ultimate fate of these cells remain to be clarified. To obtain additional information pertaining to these questions a technique of local labeling of the thymus was developed. Two DNA precursors were employed, viz., ^{125}I-iododeoxyuridine, a thymidine analog which is poorly reutilized following cell lysis, and ^{3}H-thymidine, a more efficiently reutilized precursor. Comparison of DNA renewal measured with these two compounds permits an estimation of thymidine reutilization and by inference, cell death.

The results indicate that the vast majority of newly formed thymic lymphocytes die after a short life span and only a small percent ($<5\%$) accumulates in peripheral lymphoid tissues as longer-lived cells. Thymus-derived radioactivity was detected in the spleen, lymph nodes, and bone marrow, however the largest proportion accumulated in the intestine. Since the intestine is a site of constant and intensive antigenic exposure, these data would fit the hypothesis that thymocyte migration is influenced by immune reactions. To test this concept further similar experiments are being conducted in germ-free mice and in conventional mice injected with antigens in areas other than the gut.

STUDIES ON HYPERTENSION

The experimental studies centered on two strains of rats with opposite genetically determined predispositions to hypertension. One strain, the susceptible or S-strain, rapidly and predictably develops severe hypertension in response to a variety of putative hypertensinogenic stimuli to which the other strain, the resistant or R-strain, responds only mildly or not at all.

Inter-Strain Kidney Transplants

It is generally agreed that the kidney plays a central role in the pathogenesis of hypertension, but its precise role is widely disputed. By transplanting S renal homografts into R rats and vice versa, we found that the genotype of the renal homograft was more influential in the subsequent development of blood pressure than was the genotype of the host rat. These results indicate that the kidneys of S-strain rats had a greater hypertensinogenic and lesser antihypertensive effect than R-strain kidneys. We concluded, therefore, that genetically controlled factors, operating via the kidney, can chronically modify blood pressure.

Cadmium Exposure and Hypertension

In this century cadmium, a toxic metal, and cadmium compounds have been increasingly used in industry, causing a sharp increase in environmental pollution. In man, cadmium has been implicated as a possible etiologic factor in hypertension and arteriosclerotic heart disease. We have studied the genetic influence on cadmium-induced elevation of blood pressure in our unique R and S strains of rats. Our results have shown that only the S strain rat, when exposed to cadmium, exhibited increases in blood pressure and accompanying kidney and liver damage. Furthermore, if these experimental models have relevance to "essential" hypertension in man, they suggest that even if current environmental cadmium pollution is not of immediate concern to "all" individuals, it may be a greater health hazard to "sensitive" individuals with a family history of hypertension.

Stress and Hypertension

R and S rats were exposed to a psychologically stressful situation. The stress, an approach-avoidance conflict, is considered by psychologists to be a reasonable experimental analogue to the type of situation humans find stressful. Specifically, the rats were required to perform a response in order to obtain food. However, the same response resulted in the application of an electric shock. The rats were exposed to this conflict daily for 26 weeks. S-strain rats and R-strain rats responded in a similar behavioral fashion. However, the blood pressure responses were dramatically different. Stressed rats of the R strain had an average systolic blood pressure of 126 mm Hg, while R-strain control rats averaged 128 mm Hg. Susceptible rats exposed to stress averaged 162 mm Hg, while the susceptible controls averaged 143 mm Hg. Hence, as is the case with other stimuli, the hypertensinogenic effects of stress are selectively efficacious according to genetic predisposition.

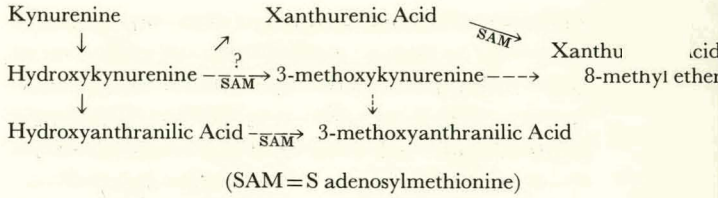
Clinical Studies

In our clinical studies, emphasis is placed on the role of salt and its excreting agent, chlorothiazide, in the treatment of essential hypertension. In 32 patients with essential hypertension, eleven patients were placed on a low salt diet (1 g NaCl per day), while the remaining 21 received chlorothi-

azide (a diuretic) with a high salt diet (10 g NaCl per day). All patients remained in our hypertension pavilion for 21 days under identical metabolic conditions. During the study period, plasma renin activity, aldosterone, and sodium and potassium excretion were measured repeatedly. The major results of this investigation were that patients put on a low salt diet exhibited a significantly greater reduction in blood pressure than the patients treated with chlorothiazide plus a high salt diet. Additionally, there was a significant positive correlation between the therapeutic effectiveness of chlorothiazide and increased plasma renin activity indicating that the antihypertensive effects of this diuretic may be directly mediated through its hyperreninemic action.

TRYPTOPHAN METABOLITES IN PRODUCTION AND CONTROL OF DIABETOGENIC ACTIVITY IN THE BODY

Xanthurenic acid (XA), a product of the metabolism of the amino acid, tryptophan, was first shown to produce experimental diabetes in animals. Then XA was shown to form a binding complex with insulin. The theory has been that vitamin B_6 deficiency or excess fat in the diet causes a high production of XA in the body, which may combine with insulin forming a complex, which, in turn, reduces the activity of insulin and causes diabetes. Another product of tryptophan metabolism in the body is the 8-methyl ether of xanthurenic acid (XAE), which also complexes with insulin, but which enhances its activity. This group of compounds and complexes presented a system of lipid-carbohydrate metabolism control and emphasized the importance of determining the source of the body xanthurenic acid, and/or 8-methyl ether of xanthurenic acid and the control of the pathways for their synthesis. The exact mechanism and immediate precursor necessary for the formation of the 8-methyl ether of xanthurenic acid are still questionable. XAE is a known carcinogen, and tryptophan metabolites, which may be precursors of XAE, occur in large concentrations in the urine of patients with either bladder or breast cancer. Information concerning the methyl group source, the role xanthurenic acid might play as a precursor, and correlation of urinary levels of XAE with other tryptophan metabolites would elucidate the XAE formation pathway. This mechanism is important in the pathology of several diseases.



(SAM = S adenosylmethionine)

To investigate the possible pathways, human subjects were given L-methionine-methyl-^{14}C, L-kynurenine-keto-^{14}C, 3-hydroxy-L-kynurenine-keto-^{14}C, or xanthurenic acid-4-^{14}C. Analysis of urine by ion exchange chromatography, paper chromatography, and carrier isolations showed that the methyl group of xanthurenic acid 8-methyl ether accounted for 0.005-0.038% of the dose of L-methionine-methyl-^{14}C. Keto-^{14}C labeled L-kynurenine and 3-hydroxy-L-kynurenine were both converted to xanthurenic acid 8-methyl ether, and accounted for only 0.015 and 0.028% of the dose, respectively. Xanthurenic acid-4-^{14}C also gave rise to labeled xanthurenic acid 8-methyl ether in four human subjects, with this metabolite accounting for 0.045-0.15% of the dose. No urinary 3-methoxykynurenine was detected, but labeled 3-methoxy-anthranilic acid (from L-methionine-methyl-^{14}C) was detected. These data indicate that xanthurenic acid may be methylated directly to form xanthurenic acid 8-methyl ether in human beings. Since 3-methoxykynurenine could not be detected, it is suggested that 3-methoxyanthranilic acid is formed by methylation of 3-hydroxyanthranilic acid rather than from 3-methoxykynurenine, although the transient presence of the latter could not be excluded.

Studies of the effects of vitamin therapy on these mechanisms may provide insights concerning control of xanthurenic acid production and subsequent maintenance of human beings with diabetes.

PHYSIOLOGY OF ERYTHROPOIESIS AND REGULATION OF ERYTHROPOIETIN PRODUCTION

Erythropoietin (Ep) production by renal glomerular cultures has been increased by addition of cobalt acetate at 10^{-6}M and by supplementing tissue cultures with added folate and vitamin B_{12}. To date however, the productivity of the cultures has not been sufficient to provide a source of pure Ep for clinical application. Renal failure anemia is associated with low Ep production. In view of the clinical needs for a source of Ep to treat anemia of renal failure and to evaluate its effectiveness in other anemias of unknown cause, efforts

continue with the objective of showing feasibility of producing human Ep continuously in tissue culture. ^{55}Fe cytocide of differentiated red cell precursors in the bone marrow has detected the presence of a feedback loop in bone marrow from the differentiated erythropoietic compartment to the pluripotent stem cell. The decrease in size of red cell precursors is sensed by the pluripotent stem cells. These then differentiate down the red cell pathway by an unknown stimulus, depleting the stem cell compartment.

Regulation of Granulopoiesis

Regulation of granulocytopoiesis has been studied by induction of sterile inflammation in dogs, and by transplantation of a murine colony stimulating activity (CSA) producing tumor. This tumor was found in mice treated with ^{55}Fe. It produces a striking granulocytosis before animals die from the malignant tumor. It can be maintained in tissue culture (suspension or monolayer) and produces CSA in substantial amounts in culture. Upon transplantation into mice one sees, in order, a mobilization of marrow granulocytes, a granulocytosis, increase in splenic cellularity and splenic stem cell content commencing three days after inoculation, along with a small increase in bone marrow granulocytic stem cell content. The sum of these studies leads one to believe that CSA has an *in vivo* effect in producing an increased number of mitoses in the granulopoietic proliferating pool, thus amplifying the output and also increasing the size of the pluripotent and granulopoietic stem cell pools. Accordingly, two mechanisms are operating to increase granulocyte production rate. Whether the signal to increase size of pluripotent stem cell pool is a primary effect of CSA or secondary to its effect on more mature cells is not clear.

MEDICAL STUDIES OF MARSHALL ISLANDERS ACCIDENTALLY EXPOSED TO RADIOACTIVE FALLOUT

In 1954 a fallout accident in the Pacific resulted in irradiation of 243 Marshall Islanders, 86 on Rongelap and 157 on Utirik atolls, and in addition 28 American servicemen on Rongerik, and 23 Japanese fishermen on their vessel, the Lucky Dragon. Semiannual examinations are conducted on the exposed and a control Marshallese population by a medical team sponsored by BNL and with participation by medical personnel from the Trust Territory of the Pacific Islands and various institutions in the United States.

The group on Rongelap was more heavily exposed than those on the other islands and showed temporary depression of blood elements and transient skin burns and hair loss. Though significant internal absorption of radionuclides occurred no associated acute effects were noted. This is notable in view of the effects of the absorption of radioiodines, from ingestion of contaminated food and water on the island, that developed later.

Follow-up examination during the first decade after subsidence of acute effects showed few clear-cut findings related to radiation exposure except possibly a temporary increase in miscarriages in the exposed Rongelap women. However, after the first decade significant late effects of radiation exposure have developed, the most serious resulting from injury to the thyroid gland. This was heralded by growth retardation in some of the exposed Rongelap children due to thyroid hormone deficiency, followed by the development of thyroid nodularities in the exposed Rongelap people. The following table summarizes the prevalence of thyroid tumors in the various groups at this time.

Thyroid Tumors – Marshallese

Group	Total	% of children* (<10)	% of adults (>10)	Cancer
Rongelap*	35% (30/86)	69	17.5	4.7%
Utirik	6.4% (10/157)	1.7	9.1	1.9%
Unexposed	5.7% (23/403)	1.6	6.4	–

*Includes both Rongelap and Ailingnae groups; age at time of exposure.

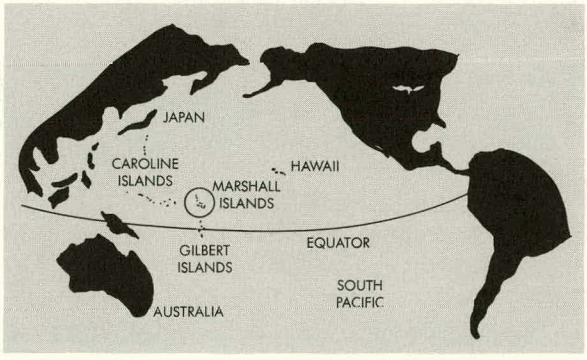


Figure 11. Location of the Marshall Islands (circled), site of annual examinations by the BNL medical team.

The considerably greater number of tumors in the Rongelap children exposed at less than 10 years of age is believed related to greater thyroid radiation doses in that group due to the smaller sizes of their glands. Benign nodules have also developed in one of the children exposed *in utero*. Dose estimates for the Rongelap adults (gamma + radioiodine radiation) were about 335 rads and between 700 and 1400 rads in young Rongelap children. On Utirik the adult thyroid dose was about 30 rads and in young children up to about 90 rads. Recently there appears to be an increasing number of thyroid tumors in the Utirik population which may be related to a longer latent period with lower doses.

Thyroid surgery has been performed in the United States on a total of 36 Marshallese: 25 Rongelap, 7 Utirik, and 3 unexposed Rongelap people. Seven cases of cancer of the gland were found in four exposed Rongelap and in three exposed Utirik people. The remainder of the diagnoses were benign adenomatous nodules. Most of these patients had extensive examinations at the Medical Research Center at BNL prior to surgery elsewhere. Thyroid hormone treatment of the exposed Rongelap people, begun in 1965, has been very important in the prevention of the development of hypothyroidism in surgical cases and the enhancement of growth in retarded children, but has been of questionable value in preventing further nodule developments.

In 1972 an exposed Marshallese boy died of acute leukemia possibly related to radiation exposure. Because of this and also due to the need of surveillance of the thyroid treatment program a resident physician was placed in the Marshalls. The acquisition of a survey ship (an LCU) in 1975 has greatly facilitated the carrying out of examinations.

IN VIVO MEASUREMENT OF RADIONUCLIDES IN MAN, KINETIC STUDIES, AND *IN VIVO* NEUTRON ACTIVATION ANALYSIS

A long range objective of this program is the development and application of techniques for the measurement of internally deposited radionuclides. Studies on control of calcium metabolism focus on disorders with losses of calcium from the skeleton (osteoporosis), and osteodystrophy associated with chronic hemodialysis. Kinetic tracer studies employ ^{47}Ca to provide the data for compartmental analysis along with data from whole-body counting and *in vivo* neutron activation analysis of whole-body calcium. The paramount need for the *in vivo* measurement of absolute levels of internally deposited radionuclides occurs in the diagnosis of cases of accidental intake of radionuclides.

The emission of krypton-85 from nuclear reactors constitutes a potential radiation hazard to an exposed population. The hazard is due not only to external radiation but also to internal radiation following inhalation of the gas. To evaluate the degree of the internal radiation hazard it is necessary to know several biological parameters of behavior of ^{85}Kr in human beings. Estimation of radiation dose requires that the rate of reaching tissue equilibrium concentrations of ^{85}Kr be determined. The objective of this study is to determine the partition coefficients for ^{85}Kr into human tissues as well as their saturation and desaturation rates.

These biological parameters have been measured in 15 normal healthy subjects after inhalation of tracer amounts of ^{79}Kr. The BNL whole body counter is used to follow the uptake, distribution and excretion of the inhaled ^{79}Kr. The pharmacokinetics of ^{79}Kr were examined by computer analysis based on respiratory parameters of each individual.

The unique Brookhaven designed total-body neutron activation analysis (TBNAA) facility has created a number of new research possibilities. The neutron irradiation facility (Fig. 12) employs an array of 14 encapsulated sources containing 50 Ci of ^{238}Pu-Be, positioned above and below the supine patient. In this techique, the neutron-induced radioactive elements are measured with the BNL whole-body counter.

A new type (prompt-gamma) neutron activation facility is now being completed for the analysis of cadmium and nitrogen in human subjects. Studies, to date, have involved only measurements in phantoms.

The clinical usefulness of the TBNAA technique is best demonstrated by the current measurement of total-body calcium. This measure provides useful data for the diagnosis and management of metabolic bone disorders such as osteoporosis. While most of the applications, to date, have involved calcium and phosphorus measurements, the measurement of sodium and chlorine by TBNAA may also prove useful clinically.

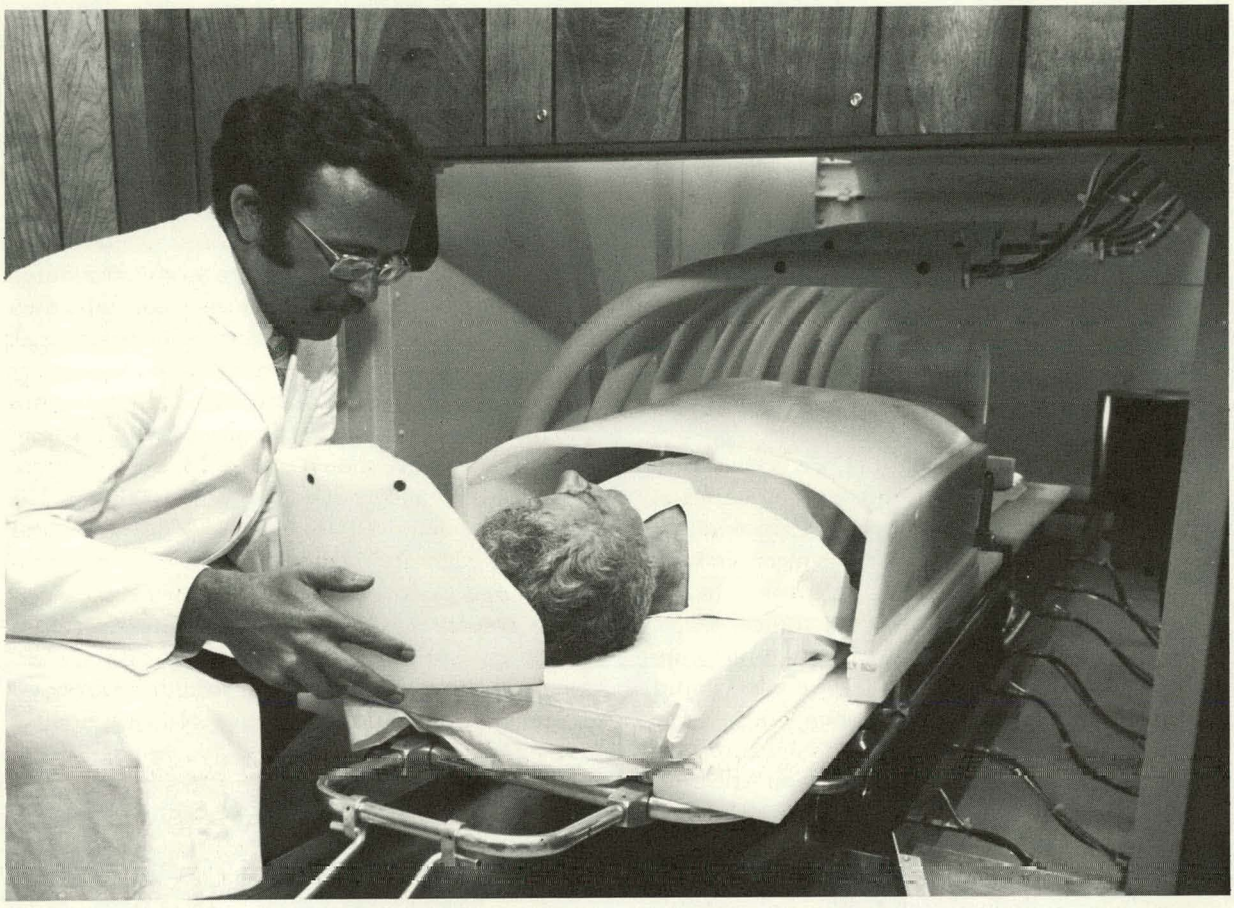


Figure 12. ^{238}Pu,Be neutron irradiation facility. Patient is positioned as shown between upper and lower guide tubes which are used to position fourteen 50-Ci ^{238}Pu,Be neutron sources.

In the osteodystrophy observed in patients with renal failure, disorders of both calcium and phosphorus metabolism, as well as electrolyte disturbances, are studied. The measure of the total-body levels of these elements provides the clinician with useful data for the design of appropriate therapeutic treatment.

Study of body composition in normal subjects continued with the determination of the body content of calcium, phosphorus, sodium, and chlorine as a function of age, sex and race. A total of 60 white and 60 black normal subjects, ranging in age from 30 to 80 years, will be measured by TBNAA. Presently it is feasible to measure only elements of high abundance in the body but with further modification of the techniques, it may be possible to measure magnesium. These data are required as a comparison reference for the data obtained in the various metabolic diseases under study and provide basic information on the elemental composition of man.

A long-term study of 100 post-menopausal women was initiated to determine if there is an identifiable group of women who are at risk for the development of post-menopausal osteoporosis, and to determine whether estrogen administration at menopause can prevent the development of clinically evident osteoporosis. The body content of calcium is determined by neutron activation analysis at the beginning of the study and repeated at one year intervals. It is predicted that a subgroup of this population will exhibit an accelerated rate of loss of skeletal mass.

A correlation of skeletal calcium mass and muscle mass in man was undertaken because of increasing interest in the characterization of the aging process in terms of body composition. For example, shortly after cessation of growth, there occurs a decrease in the protein mass that may indicate the start of senescence. Total body po-

tassium (TBK), used as an index of cellular mass, has been observed to decrease with advancing age; concomitantly, a loss of total-body calcium (TBCa), as evidenced by the degree of osteopenia, is observed, particularly in post-menopausal women. The TBK/TBCa ratios are constant for normals over the age range studied. The males have more cellular mass (TBK) per unit skeletal mass (TBCa) than the females, as indicated by their respective TBK/TBCa ratios.

DEUTERIUM ISOTOPE EFFECTS ON ANTIBODY RESPONSES

The discovery of deuterium (D or ^2H) in 1932 created an intense interest in the significance of the replacement of hydrogen by deuterium in biological systems. Most studies were concerned with the deleterious effects of deuterium (as heavy water, D_2O) on algae, bacteria, molds, seeds, higher plants, and protozoa. The reports on mammals dealt with toxicity, lethal dose effects, and alteration of metabolic rates when body water was replaced by D_2O. Mammals (mice, rats and dogs) seldom survive more than 35% substitution of D_2O for H_2O in their body fluids. There is scant information available on the effects of heavy water on immune systems. Since heavy water may be used in large amounts in future energy systems, deuterium effects on immune reactions resulting from the possible release of D into the environment are of biological concern. This research deals with the effects of D_2O presented in drinking water on antibody responses in mice.

Primary and secondary tetanus antitoxin responses were elicited in BNL mice maintained on 10, 20, 40, 60, and 75% D_2O. Primary responses were elicited either with adsorbed tetanus toxoid or fluid toxoid, secondary responses were elicited with fluid toxoid. These toxoids are normally used in man to initiate active immunity to tetanus. Antibody responses were determined by the capacity of the sera to neutralize potent tetanus toxin. Primary antitoxin responses to fluid tetanus toxoid (FTT) are shown in Fig. 13. Sera were obtained 14, 28, and 42 days after immunization. The mice were given 10, 20, and 40% D_2O in their drinking water for 10 days prior to primary stimulation and maintained on D_2O during their primary responses. The various amounts of D_2O increasingly suppressed and delayed antibody formation. Primary antitoxin production was completely inhibited in mice given 40% D_2O; none of these animals died.

The effects of 25, 40, 50, and 75% D_2O on secondary antitoxin responses are shown in Fig. 14. These animals were given a primary immunization of adsorbed toxoid when 4 weeks of age. Six weeks later, they were placed on the various amounts of D_2O for 10 days prior to their second

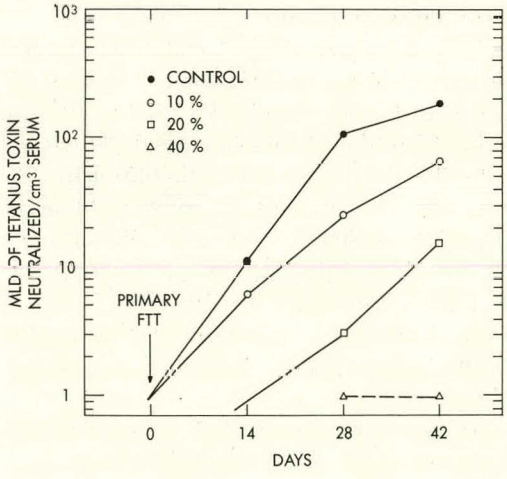


Figure 13. Primary tetanus antitoxin responses in mice immunized with fluid tetanus toxoid (FTT). Each point represents a group of 20 mice. Heavy water (D_2O) in amounts of 10, 20, and 40% was given daily in their drinking water.

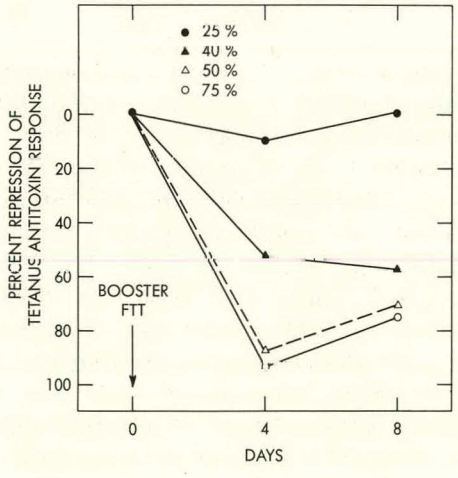


Figure14. Secondary tetanus antitoxin responses in mice given a booster injection of fluid tetanus toxoid (FTT). Each point represents a group of 20 mice. Heavy water (D_2O) in amounts of 25, 40, 50, and 75% was given daily in their drinking water.

(booster) injection of FTT. D_2O was also given in their drinking water during the 8-day period of the secondary antitoxin responses. Although 25% D_2O did not significantly alter antibody formation, 40, 50, and 75% D_2O greatly suppressed secondary antibody responses. Many of the mice died when they were given 50 and 75% D_2O daily for another week. Even though radiation was not involved with D_2O, the observed differences in dose sensitivity of primary and secondary antibody responses to D_2O was similar to the previously observed radiosensitivity of primary and secondary antibody responses after exposure to graded doses of ionizing radiation.

All mice drank less water daily as the amounts of D_2O were increased in their drinking water. A severe loss in body weight occurred as the D_2O was increased from 30 to 50%. Severe atrophy of the thymus and spleen was observed with the higher levels of D_2O. In contrast, lower amounts (2.5 to 20%) given daily over a period of 60 days resulted in an increase in the size of the thymus and spleen. These doses of D_2O, however, inhibited primary antibody responses. The minimal threshold dose of heavy water needed to inhibit primary immunization is being determined.

DNA POLYMERASES AND THEIR INTERACTION WITH POLLUTANTS

Animal tissues contain at least three DNA polymerases, enzymes that synthesize DNA, the genetic material of cells. These have been designated DNA polymerase α, β, and γ. The way in which these three enzymes function in the complicated system of DNA replication during cell division is little understood.

The burning of fossil fuels releases into the atmosphere a number of trace metals which eventually find their way into humans. Several metals can be shown to produce either mutations or cancer in animals, but it is not known whether the low concentrations found in human beings are dangerous from this point of view.

Studies are being carried out designed both to improve our understanding of the function of the DNA polymerases and to determine whether or not trace metals at low concentrations will interfere with their action.

In the chicken red cell series it has been found that there are relatively large amounts of both polymerases α and β in cells that are still dividing, but as cell division ceases the amount of both polymerases begins to decline, the α-polymerase declining slowly and the β-polymerase more rapidly. Whereas the α-polymerase is relatively easily extractable at all stages, in dividing cells the β-polymerase is firmly bound in the cell nucleus and requires strenuous conditions to extract it. As soon as cells cease to divide, the β-polymerase becomes much more easily extractable. Although some investigators feel that the α-polymerase is primarily responsible for synthesis of new DNA these results suggest that the β-polymerase is also intimately involved. Chicken red cells were used in this study because, unlike mammalian red cells, they retain a nucleus, even in mature circulating erythrocytes.

The ability of various trace metals to inhibit the DNA polymerase reaction has been studied with human DNA polymerase β. While some metals such as nickel and cobalt inhibit only at relatively high concentrations, others such as copper, lead, and mercury inhibit the polymerization significantly when present at very low concentrations. Mercury produces measurable inhibitions at a concentration approaching that in normal human blood.

GUT PENETRATION BY PARTICLES

Particulate materials, including known carcinogens and sulfates, constitute a major proportion of pollutants in the biosphere. It is generally agreed that the greatest risk of human and animal exposure to airborne particles is via the pulmonary system. Studies on pulmonary clearance have shown, however, that a large fraction of intratracheally injected or inhaled particles reappear in the digestive tract. In addition, exposure to particulate contamination of food and water supplies is almost exclusively via the gastrointestinal tract. Consequently, the mucosal surface of the intestine is a major site of contact with the external environment whether the initial exposure to the particulate pollutant is via the pulmonary or gastrointestinal tract. Little is known about the penetration of particulates through the gut wall, and the biological effects which may result.

Experimental animals have been employed in an attempt to describe qualitatively and quantitatively the uptake, total body burden, organ distribution, and fate of various particles administered into the gut either by gastric lavage or through ingestion of contaminated food and water. Polystyrenebutadiene (latex) particles are particularly

useful in these studies since they can be tagged by radioiodination, and can be made in various uniform sizes with known surface charge. Results to date indicate that a variety of particles penetrate the intestinal mucosa and can be found in liver, mesenteric lymph nodes, and Peyer's patches. Following a single gastric lavage of isotopically labeled latex (0.2 μ diameter) the largest proportion of particle-bound radioactivity was associated with the liver. Best estimates are that only a small fraction of the dose (probably less than 0.05%) crossed the intestinal barrier. Mice maintained on drinking water containing carbon particles (0.02–0.05 microns in diameter, 1.4% solution by weight) for up to 2 months had easily visible accumulations of particulates in Peyer's patches and mesenteric lymph nodes. These experiments leave little doubt that ingested particles can pass the intestinal barrier and that this must be taken into account when considering total exposure of man and animals to particulate pollutants and their potential biological effects.

EVALUATION OF LONG-TERM EXPOSURE TO TRITIUM

The objective of these studies is to determine the toxic effects of tritium (the radioactive isotope of hydrogen) in the mammalian system. Special attention is given to the effects on the blood-forming tissues and reproductive systems of experimental animals that continuously imbibe water containing tritium.

Groups of male and female mice have been maintained on tritiated water at a concentration 100 times the current maximum permissible concentration guidelines. After 26 weeks or more the bone marrow is tested for any changes in its ability to grow following transplantation into other lethally irradiated mice. Results indicate that there is some reduction in the viability of the bone marrow in these animals.

Other mice have been bred and the offspring kept on tritiated water until they are young adults. These second-generation animals are then bred and the pregnant females are examined to determine whether the tritiated water regimen has had any effect on the number of live embryos they produce. Results indicate that there is a reduction in the number of live embryos produced by the female when both she and her breeding partner, as well as their parents, had been given the tritium.

Other mice are being given nonradioactive toxic compounds to compare the effects of these with the radioactive tritium.

APPLIED ENERGY SCIENCE

DEPARTMENT OF APPLIED SCIENCE

INTRODUCTION

In response to the national emphasis on energy production, utilization, and conservation – expressed in the establishment of the Energy Research and Development Administration (ERDA) – the trend to initiate and develop programs relating to energy and the environment in the Department of Applied Science, already apparent in 1972, has continued and accelerated. The scientific programs of the Department cover a wide spectrum of subjects in the physcial, biomedical, and environmental sciences and in engineering. Many of the problems studied require a multidisciplinary approach, involving collaboration between groups within and outside the Department and combining disciplines as disparate as chemistry, medicine, meteorology, economics, geology, urban planning, computer science, and many others.

In recognition of the Department's involvement in specific areas and to improve the effectiveness of its work in all areas, the programs of the Department were regrouped, in January, 1976, into several major areas: environmental programs, energy programs, chemistry and materials programs, and reactor safety, in addition to the National Neutron Cross Section Center and the Technical Support Organization. Although the choice is arbitrary, the activities within the Department are described under these headings in what follows.

ENVIRONMENTAL PROGRAMS

Studies relating to the environment and the impact of energy-related activities upon it are grouped into four categories: (1) Oceanographic Sciences; (2) Atmospheric Sciences; (3) Land and Fresh Water Environmental Sciences; and (4) Process Technology.

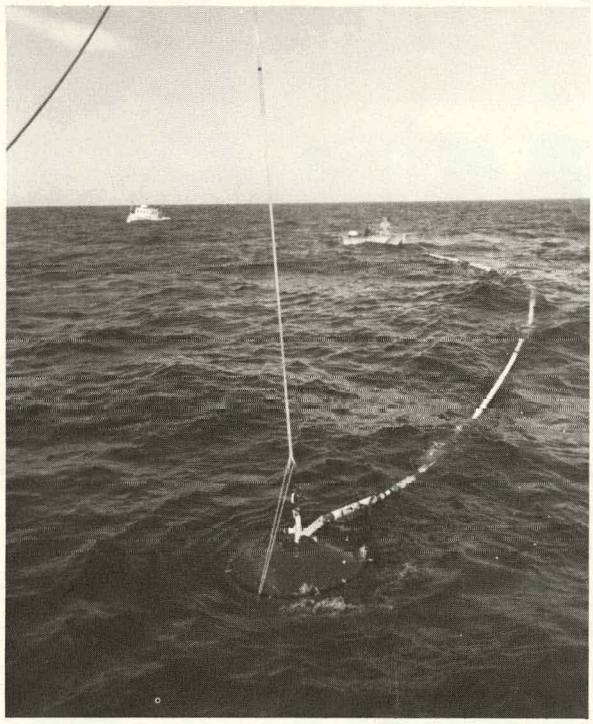


Figure 1. A 30.5-m long buoy is lowered into position. Attached to a battery pack that both provides power and anchors the buoy in place, the instrumental buoy will extend from the bottom to above the water's surface. Its transceiver will allow it to communicate directly with BNL, receiving commands and sending data on current velocity and direction, water salinity, and temperature at four different depths, as a function of time.

A linear array of four such buoys, located at different distances off-shore, constitutes the major data gathering part of the Coastal Boundary Layer Transect (COBOLT) experiment of the Oceanographic Sciences Division.

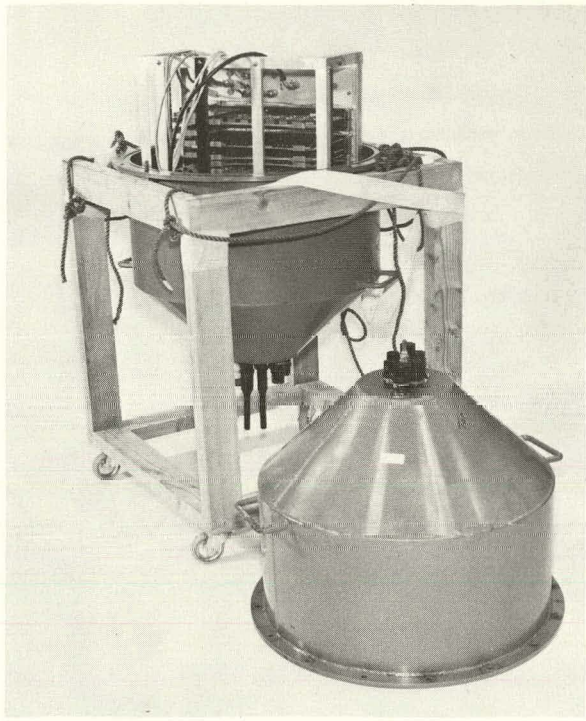


Figure 2. Data processor package (designed and built by the Instrumentation Division) with top part of housing removed. This package is located on the spar buoy approximately one-third of its length from the top (surface). It provides the buoyancy necessary to keep the spar in an upright position.

OCEANOGRAPHIC SCIENCES

Interest in the coastal shelf has been stimulated in the past few years by the possibility of locating floating nuclear power plants, off-shore tanker facilities, and oil-drilling activities in this region.

Understanding of the natural variability and of the pathways of energy flow of marine ecosystems on the continental shelf is the necessary prerequisite for assessment of man's potential perturbation of these systems. A multi-discipline, multi-institutional (Woods Hole Oceanographic Institute, Lamont-Doherty Geological Observatory, State University of New York at Stony Brook, and several others) research program has been initiated at BNL to study the coastal waters between Cape Hatteras and Cape Sable. An electromagnetic current meter system has been developed that is sufficiently sensitive to sample the currents, temperature, and salinity of the upper waters of the ocean, where most of the biological productivity occurs. These data are telemetered ashore to BNL to provide a real-time assessment of the physical variability of the habitat. Multi-ship cruises acquire data on the sources of nutrients for the continental shelf, the growth and death of organisms, their distribution in time and space, the amount of recycling of material between the water column and sediments, and the biological response to natural perturbations of the systems, such as storms or internal waves. Laboratory studies of remineralization by bacteria, of potential growth of algae, of grazing by dominant herbivores, and of survival of fish larvae are integrated with this field work to explain and predict the probable modes of response to transients within the continental shelf ecosystem. A systems approach, involving a group-research effort with feedback between numerical models and field and laboratory data, has been

adopted both as a means of synthesis and as a focal point for future management of the highly complex ecosystems of the coastal zone.

ATMOSPHERIC SCIENCES

Related to the studies in coastal oceanography is the program in the meteorology of the coastal region. Of particular interest has been the diffusion of pollutants over the ocean near the shore under the variety of atmospheric conditions that may prevail. Included in the program is the study of momentum transport at the air-sea interface. These experiments have been carried out by measuring the turbulent-eddy momentum transfer over the ocean using a specially-designed stable buoy as a platform. Coordinated theoretical and experimental studies of what happens as air flows from over-the-ocean to over-the-land and of sea breeze circulation are being made.

Atmospheric chemistry research has emphasized the measurement of the conversion of sulfur dioxide to particulate sulfate in fossil-fueled power plant plumes. There is also laboratory work being carried out on basic aerosol dynamics, the improvement of analytical techniques for the low concentrations of substances found in the atmosphere, and the development of tracer methods for following the movement of air masses.

Work has been started on an interlaboratory-interdisciplinary study of air pollution over the northeastern part of the United States. This study, called the Multistate Atmospheric Power Production Pollution Study (MAP3S), is aimed at improving the ability to predict the change in concentrations of sulfur compound pollutants that will result from changing the pattern of fossil fuel utilization in the Northeast. It builds upon the atmospheric chemistry and meteorological experience that has been developed at BNL. MAP3S will involve extensive airborne measurements, special field experiments, improvements in chemical analysis techniques, and the development of numerical models.

LAND AND FRESHWATER ENVIRONMENTAL SCIENCES

Acid Rainfall

The acidity of rainfall in the northeastern United States has increased greatly in the past ten years.

Figure 3. Smoke from generators is used to trace wind patterns. Here the behavior of winds in the wake of an island is being delineated by two plumes, one from the island and one from a ship anchored nearby.

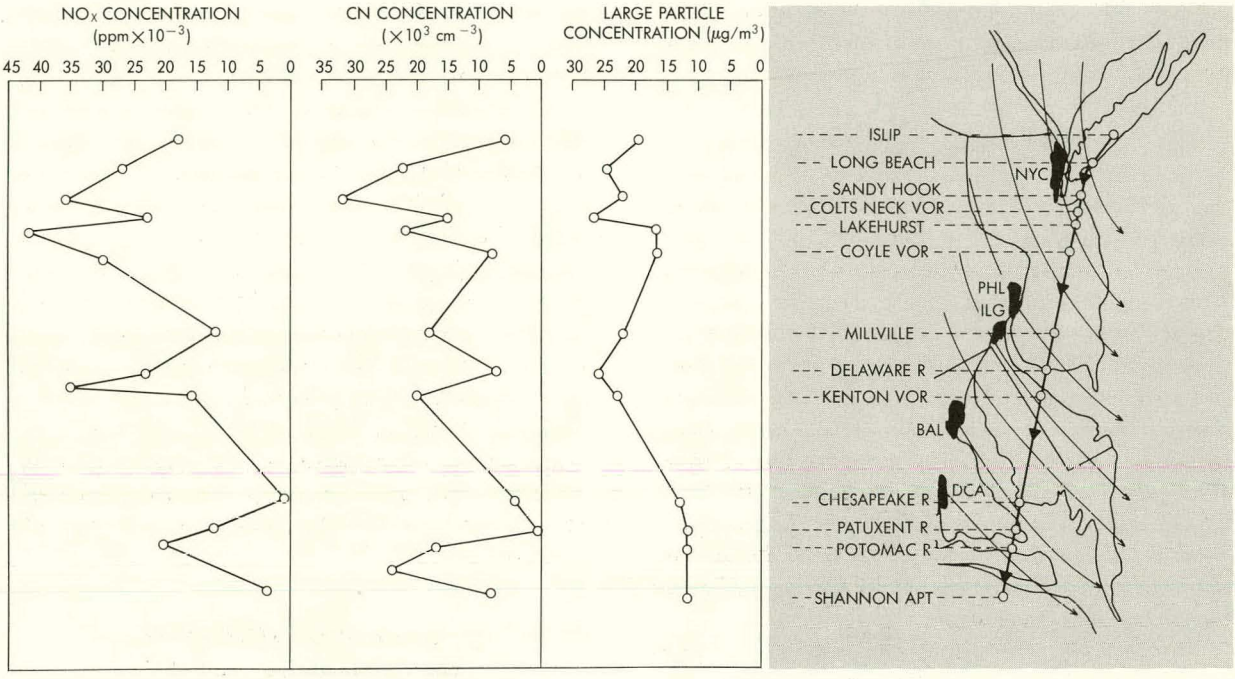


Figure 4. Airborne measurements of concentrations of particles and gases in urban plumes between Islip, Long Island and Frederickburg, Virginia are depicted here. Such investigations are part of the Department's program to study pollution, transport, and chemical transformation of gases and material over regional distances.

The cause of this appears to be related to the increase in anthropogenic sulfur and nitrogen oxide compounds, particularly from the fossil fuel generation of electric power.

The effects of this acidic precipitation on forest plants are being studied. Experiments are aimed at (1) determining the responses of plant foliage to acute and protracted doses of acidic rain, (2) elucidating the response of leaves to acid aerosols and acid rain in combination, (3) viewing microscopic effects on leaf surfaces and internal structures, and (4) following the rates of accumulation of sulfate and nitrate ions and relating this to leaf injury.

Facilities have been constructed for administration of gaseous SO_2, aerosols of various sulfates, and simulated rainfall at any desired rate and in any combination to a variety of growing plants under controlled conditions.

After the behavior of forest plants under these environmental conditions has been characterized, field experiments will be undertaken to evaluate the response of vegetation in natural ecosystems of Long Island.

Sewage Reclamation

The feasibility of land treatment of sewage to reclaim potable water and utilize nutrients in crop production has been under investigation for several years. Experiments with spray application in open systems have shown this method to be highly land-intensive and possibly productive of undesirable aerosols. Spray experiments have been succeeded by work with closed, lowland, flow-fed systems. Two lowland systems that are being compared for effectiveness in renovating sewage are the marsh/pond and the meadow/marsh/pond. Both systems have produced water that meets all determinable public drinking water standards. However, the marsh/pond system requires only half the land area that the other does. Work continues with both systems to optimize their design and operation to determine the system that is most cost-effective and least energy-consumptive in operation and least-cost for construction.

PROCESS TECHNOLOGY DIVISION

Nuclear Waste Research

Methods are being developed for managing the long-lived radioactive wastes from nuclear power reactors, for analyzing the properties of waste materials going into national burial sites, and for de-

termining the condition of these burial sites. Long-lived cesium-137 and strontium-90 wastes have been encapsulated and fixed in polymer-concrete type materials. The stability of these waste forms towards heat, radiation, and leaching by water and chemicals is outstanding. A process has been developed for incorporating waste tritium into polymer-impregnated concrete blocks having high strength and durability. The ERDA Mound Laboratory has adopted this process for permanent storage of tritium.

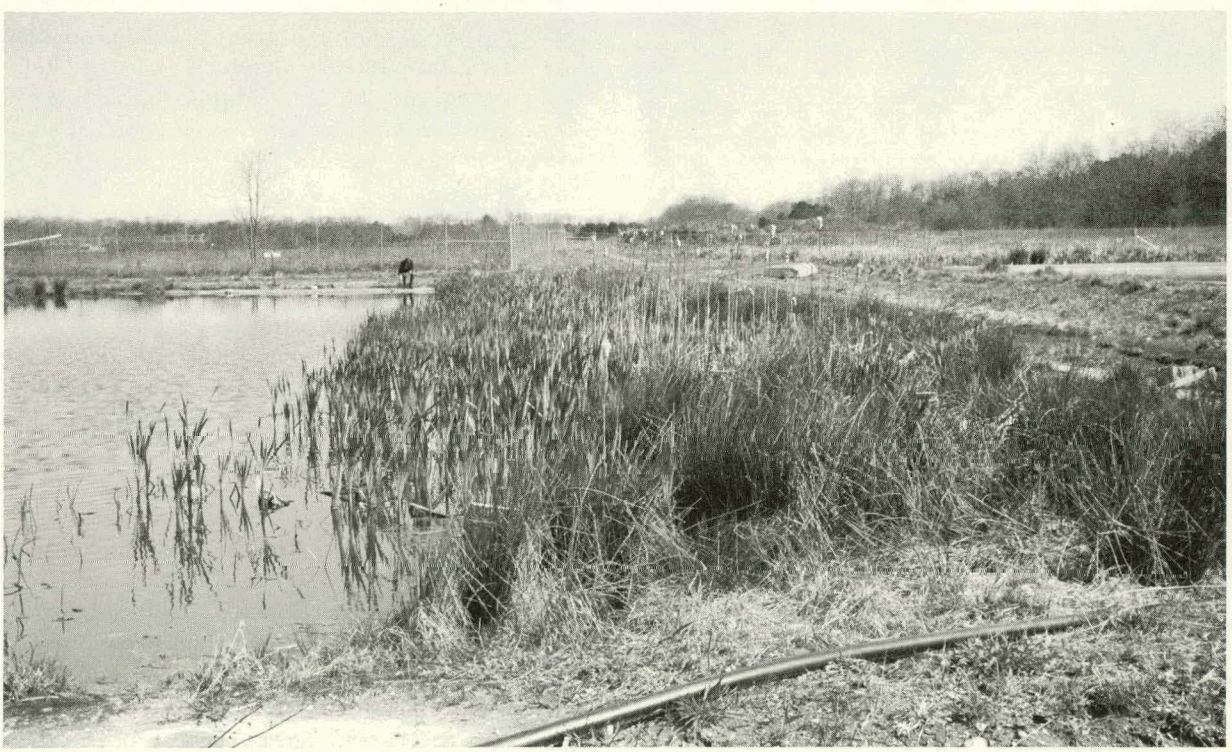
A program has been initiated to monitor the properties of waste forms going into the national burial sites and the movement of the waste within the sites.

Materials Systems

Out of the long-term materials development work at BNL on polymer-impregnated concrete and polymer concrete, a number of applications of world-wide interest have emerged. These include polymer-concrete piling, underground manhole boxes, sidewalk curbing, and building panels. Assistance is being given in technology transfer to industry. A program to develop these materials for geothermal power plant applications is underway. They are corrosion resistant and durable for handling the hot brine and steam which usually rust out metals used in piping and power plant equipment. Samples have been tested and found to be extremely durable in the steam geysers and the hot wells of the Imperial Valley in California and the Bacca wells in New Mexico.

Under the sponsorship of the Federal Highways Administration, polymer concrete is being applied to the repair of deteriorated concrete on bridge decks. A course in the application of polymer-concrete to highway construction and maintenance

Figure 5. An experimental prototype quasi-natural 38,000 liters (10,000 gallon) per day sewage treatment system, located on the Laboratory grounds, is shown here. The influent is a blend of sewage, cesspool pumpings, and sludge. The effluent is recharged into the ground water with greatly reduced nutrients, including nitrate, fecal indicator bacteria, and suspended solids. Two experimental systems are operating side by side: a meadow planted in Reed Canary grass, followed by cattail marsh, followed by a shallow pond, and a second system consisting of a larger marsh and a pond. All these are underlain by impermeable barriers preventing premature release to the environment. Experiments are underway to determine which of the two is more efficient in removing nitrate, bacteria, pathogenic viruses, and other pollutants. Preliminary analysis indicates that both are efficient, energy conservative, and much less costly than conventional sewage treatment systems.



has been given to 37 State Departments of Transportation around the country. In cooperation with the N.Y. State Department of Transportation, repairs have been made on the Major Deegan Expressway, a major artery in New York City, without stopping the 85,000 car-per-day traffic. In one hour, polymer concrete can set and achieve a strength greater than cured concrete. The deck of the Greenport Bridge in Suffolk County is being resurfaced with a monomer-soaking technique.

Methods are also being developed for reinforcing stone carvings and monuments by monomer soaking. The brownstones at the Brooklyn Museum have been preserved by this method.

Urban waste materials have been incorporated into useful products, one of which is glass-polymer composite sewer pipe, using the glassy fractions from municipal waste. Eight-inch pipe was installed in the Town of Huntington two years ago with good results. Twelve-inch pipe has recently been installed in the Newark, New Jersey, sewer system.

Coal Conversion

A flash hydropyrolysis process is being developed to convert coal to liquid and gaseous hydrocarbon products. The reaction between fluidized fine coal particles and high-temperature gas takes place in a tubular reactor over a period of less than 30 seconds. The products formed are benzene, light oils, and methane and ethane bases. Conversions of over 60% have been obtained on North Dakota lignite. The process can be integrated with a refinery to produce gasoline.

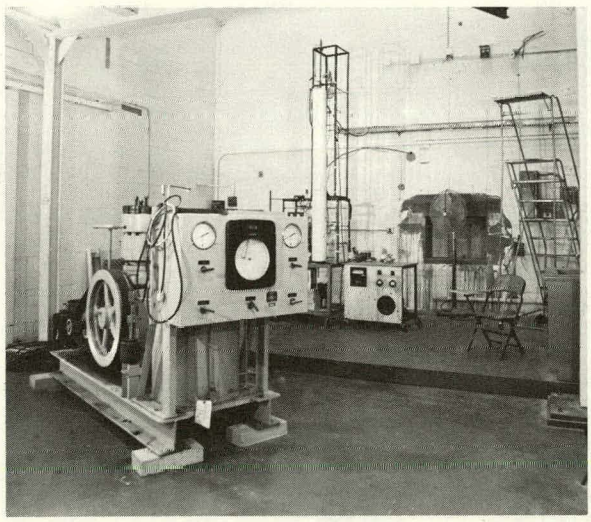


Figure 6. A small scale experimental unit for studying the batch flash hydropyrolysis of coal to liquid and gaseous products is shown in the background. In this same area a larger scale, continuous experimental unit is presently under construction. In the foreground the high pressure diaphragm compressor for this larger unit can be seen.

Advanced Systems

A study is being made of the potential use of magnetic fusion reactors for chemical and material processing. Energy in the form of neutron, gamma, and ultraviolet radiation can be applied to the production of synthetic fuel, synthetic food, and steel, and to the processing of municipal solid waste.

The production of synthetic fuels using nuclear power, air, and water is being evaluated. Application to the generation of fuel at sea aboard a nuclear aircraft carrier is being investigated.

ENERGY PROGRAMS

These programs span the spectrum from analytical studies such as technology assessment, economic analysis and energy model data base handling to laboratory and small scale engineering studies of the production, storage and utilization of hydrogen, energy management in residences and small commercial buildings, the biomedical and environmental assessment of power production, and magnetic fusion technology. Elements of these programs interact with complementary studies at the local, regional, national, and international levels.

National Center for Analysis of Energy Systems

The energy systems analysis program, begun for the Office of Science and Technology and the Atomic Energy Commission, has evolved into the National Center for Analysis of Energy Systems (NCAES). It is designed to assist the Energy Research and Development Administration in the formulation and execution of a balanced and diverse energy research and development program that is responsive to the nation's needs. The programs carried out at the Center are comprehensive and interdisciplinary, allowing the detailed study of the complex interrelationships between technological, economic, social, and environmental factors that influence energy policy. In order to relate the technological aspects of energy to other policy

areas including economics and the environment, work is performed, when appropriate, for other Federal agencies and for State and regional agencies, regulatory bodies, and planning groups. The emphasis of the programs at the Center is on planning studies at the regional, national, and international level in areas of special impact on energy R&D policy formulation. Analytical work has been performed in support of the ERDA Research, Development, and Demonstration Plans prepared by the ERDA Assistant Administrator for Planning and Analysis. Comprehensive studies have been performed of energy strategies involving energy conservation and further electrification of the energy system.

Regional and International Planning and Analysis

The initial energy systems modeling efforts at BNL made apparent the need for analysis at a smaller geographical scale. In 1973 a program was initiated with support from the National Science Foundation to develop an energy/environmental planning framework useful for urban regions. A number of reports were prepared on that work, which took New York City as the first application. A study of the relationships between land use and energy consumption was also initiated with support from the Federal Energy Administration. That work demonstrated that significant energy savings can accrue from altered land use development patterns in suburban regions and produced a guide that can be used by planners to incorporate a concern for energy into planning. In 1974 a major continuing effort was undertaken with support from ERDA, the aim of which is to examine major energy and environmental planning issues in the Northeast. A major component of that program in 1975 and 1976 was a study of alternative energy futures for the region. In a separate study, taking New Jersey as a focus, an analysis was carried out of the economic, technical, environmental and sociopolitical implications of clustered siting of nuclear power plants.

In 1975 a number of international energy programs were initiated. In one of these BNL is providing systems analytical support to the development of research and development priorities for the countries included in the International Energy Agency. In a second project, work was initiated in formulating an understanding of the role of new energy technologies in developing countries.

Economic Analysis

A broad capability for economic analysis of energy systems has been developed. A key program involved the adaptation of a standard input-output (IO) model of the U.S. economy, by restatement of energy sector activity in physical terms rather than dollar terms, for use as a policy-oriented tool. A second program resulted in linking the modified economic model with the Brookhaven Energy System Optimization Model (BESOM). Solutions generated by the Linear Programming (LP) model are used as input to the economic model to provide indications of the economy-wide impact of new energy technologies or alternative energy policies. The combined model was applied to preliminary studies of an oil stockpiling program and a moratorium in nuclear electric power plant construction.

A further development in economic modeling involved initial work toward linkage of the IO-LP model to combine its pricing and output structures with those of interindustry and growth models developed by Data Resources, Inc. This work is continuing.

The economic models were used to provide support to ERDA Planning and Analysis in the preparation of the second annual ERDA research and development plan at the end of 1975.

In April 1976, work started on two new programs in the field of energy conservation. One is directed toward the development of analytical tools for use in the assessment of a broad range of conservation options. The other is directed to conservation in transportation models.

Biomedical Assessment

The biomedical assessment activity, now in the NCAES, was begun several years ago to assess the environmental costs of national energy options. The Reference Energy System (RES) developed by Brookhaven has proved a useful and practical way to analyze national energy options. Environmental indices are included in the RES as air and water-pollution emissions and acres (hectares) of land used. The objective of the biomedical environmental assessment activity is to translate emissions data into environmental effects whose costs can be weighed alongside direct costs of energy systems.

A basic methodology has been developed beginning with effects diagrams for the major electric fuel cycles – coal, oil, natural gas, hydro-, and nu-

clear. The effects modules describe how an emission or resource use affects water, air, land, materials, and biota, and can be used to show the difference between the initial conditions and the conditions after the introduction of the stress.

Technology Assessment

The Brookhaven Energy System Models have been used to assist both the former Atomic Energy Commission and ERDA in formulating long range R&D strategies. These models are used to assess the impacts of new technologies in terms of future economic, environmental and resource effects upon the U.S. energy system. The models have also been coupled with econometric models for the assessment of technological and policy implementations upon the entire economic structure of the nation. A *Sourcebook for Energy Assessment*, issued recently, provides a systematic methodology and data inputs for technology assessments.

Energy Data and Models

Laboratory experience in computerized data base management was applied to the development of the Energy Model Data Base (EMDB). Also developed was a companion analytical tool, the Energy System Network Simulator (ESNS). The EMDB/ESNS system was used extensively at the Laboratory in energy systems analysis projects. In addition to this use, a number of outside organizations were supplied with the system for use in their own energy systems analysis tasks, under sponsorship of the Council for Environmental Quality and the National Science Foundation.

Models developed and applied in NCAES programs include the Reference Energy System and the Brookhaven Energy System Optimization Model. These were used in the development of the ERDA Research, Development, and Demonstration plans, ERDA-48 and, most recently, ERDA 76-1. A topical report on the Brookhaven Energy System Optimization Model has been published.

Analytical support has continued for the Office of Planning and Analysis. Under a new program, beginning in 1976 analytical support will also be provided to the Long Range Strategy Division of ERDA Fossil Fuels.

Energy Storage and Conversion

What began as a program directed toward hydrogen storage for utility application has been expanded and diversified. New programs initiated in energy management and conversion during the last few years include expansion of the hydrogen technology programs, ranging from the production and storage of hydrogen to fuel cell development and cycle analysis for improved efficiency. The fuel cell program is directed toward the identification of second and third generation fuel cell systems that will be efficient, cost-effective electric conversion devices. The application of the pressure temperature relationship of hydrogen-metal hydride systems, developed in the hydrogen technology work, to new power cycles capable of utilizing low-level waste heat is the focus of the chemical compressor cycles program.

Energy management in residences and small commercial buildings is a new program, initiated two years ago and designed to have near-term impact on the conservation of fossil fuels, in particular fuel oil currently used for domestic heating and cooling. The aspects of energy management being investigated include burner/boiler design and operation, application of thermal storage, and the design of light and heat control windows.

Figure 7. A Cooperative Fuel Research (CFR) engine (center) is shown with some of its associated electronic equipment (left), a rapid scan spectrophotometer (right), and a detector for nitrogen oxides (hidden from view). Optical ports in the engine cylinder head permit *in situ* detection and identification of transient species present in the burning fuel/air mixture, and allow the experimenters to study the effects of changing various engine parameters and fuel characteristics. These data are correlated with engine emission data.

The detailed chemical kinetics of identified transients can be studied in several pieces of laboratory apparatus (not shown) so that the chemistry of the combustion process, and its dependence on engine and fuel parameters, as well as its role in determining the composition of the emissions, may be better understood.

Combustion Studies

A combustion research program was initiated two years ago to gain a better understanding of the sensitivity of combustion efficiency and emissions to variations in operating parameters when using non-petroleum based fuels. A Cooperative Fuel Research (CFR) internal combustion engine has been installed and instrumented as the test bed. Reactions identified in the CFR engine are studied in special experiments designed to study the kinetics of key reaction steps.

Magnetic Fusion Technology

Work on the technology of fusion reactor blankets has resulted in three new concepts which offer substantial improvements in blanket performance over previous concepts and have gained wide attention in the magnetic fusion energy program.

The use of solid lithium compounds for tritium breeding, instead of liquid lithium metal or fused salts, eliminates the need for liquid metal or fused salt technology with their attendant corrosion and fluid dynamic problems. A gas cooled solid blanket promises to be much simpler and more reliable. Experiments with tritium release from solid compounds show satisfactory release rates, and correspondingly very low tritium inventories in the blanket.

The use of aluminum as a structural material for blankets and shields results in blankets with extremely low residual activation. With aluminum, radioactive inventories 10 days after reactor shut-down are six orders of magnitude below those of stainless steel or refractory metal blankets. This permits hands-on maintenance capability for most parts of a fusion reactor, and greatly reduces radioactive waste problems. Blanket designs that have been developed permit thermal cycle efficiencies comparable to those for current fission reactors.

Since fusion blanket lifetime is expected to be relatively short, i.e. a year or two, because of radiation, damage, it is important to replace blankets rapidly so as to minimize reactor down time. A new modular blanket approach, termed the RIP blanket, has been developed which permits rapid replacement of the ~200 modules that form the blankets in a couple of weeks. Modules are removed through a set of relatively small access ports at the outside of the reactor shield with seals and header connections made outside. No remote maintenance equipment is required.

Advanced Conversion Cycles

A new type of power cycle has been developed that results in much higher conversion efficiences. In this cycle, the High Efficiency Power (HEP) cycle, low grade waste heat is used to operate metal hydride (e.g. $FeTiH_x$) beds that compress hydrogen by a near-reversible absorption-desorption process. The compressed hydrogen is used as the working fluid in a conventional closed, regenerative Brayton cycle with a high grade heat input (e.g. fossil or nuclear reactors), without the need for a mechanical compressor. In the HEP cycle, 80-90% of the high grade energy input can be converted to electricity, in contrast to ~40% with conventional power cycles. This cycle offers the potential of large savings both in energy resources and power generation costs. Experiments with metal hydride compressors have shown good performance, sufficient for full sized compressors.

CHEMISTRY AND MATERIALS PROGRAMS

The materials components of these programs are directed toward applied research in superconducting materials, radiation damage to materials in magnetic fusion environments, and corrosion studies associated with nuclear reactor safety. The chemistry studies comprise basic and applied chemical research in energy-related areas such as artificial photosynthesis, metal hydrides, the chemistry and physics of coal conversion processes, the electrochemistry of molten salts and intermetallic compounds, cyclic separation processes, the chemical kinetics of combustion intermediates, and several other studies.

In addition, the production of medical radionuclides and associated radiopharmaceutical research also form elements of this activity.

Superconductors for Low Loss AC Transmission Lines

In collaboration with the Accelerator Department work has been done on materials for superconducting power transmission lines. Two major requirements for a superconductor to be used in such an application are low ac losses and high current carrying capacity at the frequency employed. Towards this end, methods of treating surfaces of commercially available superconducting materials, such as Nb_3Sn, to meet these requirements have been developed. They consist of electrochemical or chemical polishing techniques to fabricate

smooth surfaces from rough Nb_3Sn tapes. Both treatments produce modified Nb_3Sn tapes that have sufficiently low ac loss characteristics and high current capacities for power transmission lines.

Composite Filament Superconductors

Power generation by fusion or magnetohydrodynamic (MHD) reactors requires the production of very intense magnetic fields in very large volumes. Superconducting magnets appear to offer a practicable and economic solution to the problem, providing that adequate superconducting materials for the magnetic windings can be produced. The requirement is high critical current density at very high magnetic field strength. A technique to improve the behavior of presently available wires has been developed.

Niobium filaments are mounted in a Cu-Sn alloy matrix, after addition of either Al or Ga to either the Nb or the alloy matrix. This is followed by extrusion and drawing down to final size. At this point in the process, the drawn composite is heat treated, inducing the formation of Nb_3Sn, alloyed with small amounts of Al or Ga. The resulting product displays suitable critical current density and magnet field properties for use in fabricating superconducting magnets for fusion and MHD reactors.

Neutron Irradiation Damage in Nb_3Sn

Magnets and their associated components, including windings, will be subjected to neutron irradiation when used in fusion reactors. Hence the response to neutron radiation damage of any material proposed for use in such an application must be established.

Nb_3Sn wires were exposed to neutrons ($E>1$ MeV) for fluences as high as 10^{18} neutron cm^{-2}. At these exposures the superconducting critical temperatures and critical currents were observed to decrease drastically. However, within the limits of uncertainty regarding actual fluences in specific fusion reactor environments, a fluence of 10^{18} neutrons cm^{-2} corresponds roughly to the predicted 10 year life-time of the reactor.

The degradation in the superconducting properties of Nb_3Sn appears to be related to the disruption of the integrity of the long chains of Nb present in the original compound.

Magnetic Fusion Reactor Materials Irradiation Facility

The needs of the Magnetic Fusion Energy program related to radiation damage to fusion reactor materials are becoming critical to the development of the planned Experimental Power Reactor. 14-MeV neutron sources with high enough fluxes ($>10^{14}$ n cm^{-2} sec^{-1}) in volumes adequate for meaningful experiments do not exist.

BNL has developed a concept to simulate a fusion reactor's 14 MeV neutrons, and has proposed the construction, based on that concept, of an intense neutron source facility capable of producing fluxes $>10^{15}$ n cm^{-2} scc^{-1}. The high-energy neutron generator will consist of a deuteron linear accelerator to accelerate continuous 200 mA beam currents to an energy of 35 MeV to produce high energy neutrons by deuteron breakup on a liquid lithium target via Li(d,n) reactions.

The deuteron beam will originate from a low emittance duoplasmatron source, be first accelerated in an electrostatic 500-kV accelerator, then

Table I

Defect Production Rates in Nb at Various Nuclear Facilities

Facility	Flux n cm^{-2} sec^{-1}	Displacement rate dpa/sec[a]	He ppm/sec[b]	dpa/He[a]
HFIR	6×10^{14}	1.49×10^{-7}	0.06×10^{-7}	24.8
EBRII-7	4×10^{14}	1.24	0.02	51.7
LAMPF	2×10^{13}	0.12	0.08	15
BENCH[c]	2×10^{14}	2.11	4.00	0.5
"14 MeV" (RTNS)	2×10^{12}	0.06	0.20	0.3
Li(d,n) (30 MeV)	1×10^{14}	2.70	6.50	0.4

[a]dpa = displacement per atom.
[b]ppm = atomic parts per million.
[c]Bench mark, calculated effects of neutrons in a typical fusion reactor taken as a standard reference.

injected into the linear accelerator for acceleration to 35 MeV. The linac is a drift tube structure operating at 50 MHz and divided into eight cavities which offers the possibility of varying the final deuteron energy between 20 and 35 MeV. The deuteron beam will be transported to the target in a long transport channel designed to control the beam delivery on the target as to time structure, spot size, etc. The beam will be stopped in a flowing liquid-lithium target capable of removing the 7 megawatts of beam power produced.

This proposed facility will be very versatile in providing adjustable neutron fluxes, variable neutron energies, and flexibility in neutron delivery from short pulses for theta-pinch simulation, to dc fluxes for steady state Tokamak simulation.

The effectiveness of this facility for radiation-damage experiments for the Magnetic Fusion Energy program is best illustrated by Table I which shows the defect production rates in Nb at various nuclear facilities. The Li(d,n) neutron source most closely approximates the spectrum referred to as BENCH(mark) in the table. That represents the calculated neutron spectrum at the first wall of a fusion reactor surrounded by a hypothetical blanket structure.

Identification of the Primary Electron Acceptor in Bacterial Photosynthesis

The primary event in bacterial photosynthesis is known to consist of the following photochemical step:

$$(\mathrm{BChl})_2 + \mathrm{Y} \xrightarrow{\text{light}} (\mathrm{BChl})_2^+ + \mathrm{Y}^-,$$

where BChl ≡ bacteriochlorophyll, the light harvesting pigment of photosynthetic bacteria. The remaining steps in the photosynthetic process are chemical in nature. The initiation of the entire process depends on the ability of Y^- to form and provide the driving force for the next chemical step. Attempts to fabricate artificial systems that mimic this basic biological process require that the identity of Y^- be known. Previous assignments of Y^- have not been consistent with all the known spectroscopic and thermodynamic data.

Comparison of spectroscopic and electrochemical data obtained at BNL with picosecond (10^{-12} sec) optical changes, recently observed elsewhere using pulsed laser techniques, has led Brookhaven workers to propose that bacteriopheophytin (BPh) is the electron acceptor in the primary photosynthetic step, according to the following process:

$$(\mathrm{BChl})_2 + \mathrm{BPh} \xrightarrow{\text{light}} (\mathrm{BChl})_2^+ + (\mathrm{BPh})^-$$

This assignment is consistent with existing data, and thus the identity of Y^- has been established.

As pictorial confirmation, a comparison between the observed spectral data and those calculated upon this assignment is shown in Fig. 8. These results confirm the rationale of the BNL study – the use of model compounds, guided by theoretical calculations, to explain and predict reactions involved in bio-energetics. In this instance, the explanation of a process that occurs within ten picoseconds was arrived at by studying intermediates, of chosen model compounds, that have lifetimes of the order of a month.

Metal Hydride Single Crystals

Metal hydrides are of importance in energy related research and development because of their potential for safely and conveniently storing hydrogen for subsequent release and use as a fuel. The determination of the detailed crystal structure of metal hydrides is one very important element in understanding hydride formation and hydride behavior. In order to unequivocally establish the structures of these materials, it is necessary to work with large single crystals. With but two

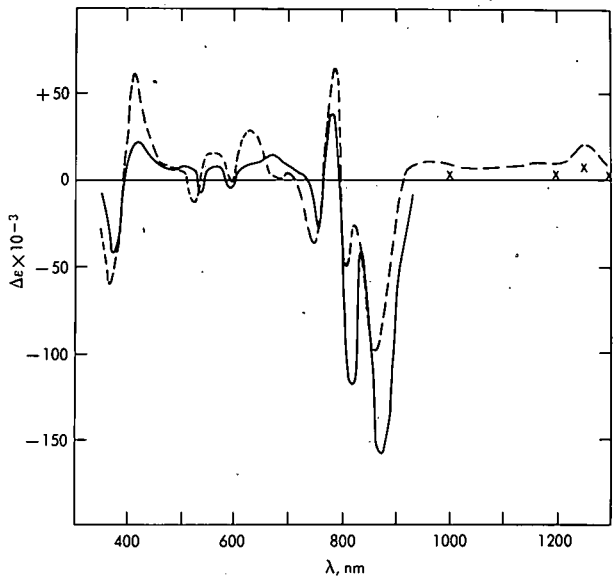


Figure 8. Comparison of the experimental picosecond, laser induced optical changes in bacterial reaction centers (—— and points X) with those calculated (– – – –) on the assumption that the process observed is the charge separation into the bacteriochlorophyll cation $(\mathrm{BChl})_2^+$ and the bacteriopheophytin anion $(\mathrm{BPh})^-$.

known exceptions, it appears to be exceedingly difficult, if not impossible, to grow large single crystals of metal hydrides by conventional crystal growing techniques.

At Brookhaven National Laboratory, a novel technique has been demonstrated to produce large single crystals of at least two metal hydrides that have not been formed before. The technique holds the promise of being developed into a general procedure for this purpose. In this procedure, the starting point is a large single crystal of the metal. The conversion of metal plus hydrogen to metal hydride is conducted, slowly, at a temperature at which both solids (solution of hydrogen in metal and metal hydride) are mutually soluble. When conversion to metal hydride has been completed, the hydride crystal can be cooled to room temperature, where it is stable and can be employed in structure determinations by both x-ray and neutron diffraction techniques.

Data on niobium and tantalum monohydrides are presently being obtained in the Chemistry Department using crystals prepared by this technique in the Department of Applied Science.

Medical Radionuclide Research

The Brookhaven Linear Isotope Producer (BLIP) completed the first phase of its operation in which the concept and the detailed design of the facility were proven satisfactory and in which shipments of selected unique istotopes (viz., iodine-127, and iron-52) were made to a number of organizations for research and evaluation. During this period the original design of the targets was radically changed; as a result, fabrication times and costs were markedly reduced, operations were made simpler and more flexible, and it became possible to examine targets visually during irradiation, thus providing better control and increasing the understanding of the effect of high proton currents on target materials. These improvements were particularly useful also because during this period the LINAC succeeded in delivering to the BLIP an average current of 92 microamperes sustained over 146 hours in a single week (13,400 microampere-hours per week). Improvements in post-irradiation processing included better chemical procedures and modifications to the equipment, which increased speed, efficiency, and therefore product quality.

Significant progress was made in several areas of radiopharmaceutical research.

A simple efficient kit for labelling a patient's red blood cells with technetium-99m for use in studies of the heart and spleen and in imaging the vascular system was developed.

Increased knowledge was obtained of the chemistry of technetium, of the role of tin, which is commonly used as a reductant in the labelling of radiopharmaceuticals with technetium-99m, and of the causes of problems encountered during such labelling procedures.

Monovalent thallium-201 was developed for use in the study of blood flow to the myocardium. The production of this radionuclide, which is currently considered to be the optimum tracer for studying myocardial infarcts, has now been taken over by industry.

Reactor Materials Safety Research

A Reactor Materials Safety program was initiated in FY 1976. It performs research and provides consulting services and technical assistance to the Nuclear Regulatory Commission in the area of corrosion and stress corrosion cracking of materials in nuclear power plants and reviews of materials performance and leak detection in LMFBR's.

REACTOR SAFETY

Work in this area is performed for and in support of the Nuclear Regulatory Commission (NRC), providing both day-to-day support to meet the Commission's regulatory needs as well as developing the tools needed to evaluate future licensing applications. In general, studies are directed towards three generic reactor types – thermal, fast, and high temperature gas-cooled reactors – and are principally of an analytical nature.

Reactor Core Safety Analysis

The general aim of this work is to provide an independent assessment of the details of reactor behavior during normal and abnormal operation for the NRC staff's use in licensing decisions. Calculations of the neutron, power, or temperature distribution throughout a reactor are done with a wide variety of computational tools that are maintained. In addition to doing independent calculations, vendor methods are audited by reviewing topical reports.

Recent studies have been concerned with three specific categories of problems. The first is the cal-

culation of power distributions during normal operation, including both steady state and transient conditions. For a pressurized water reactor (PWR), utilizing deeply inserted control rods, the reactor was represented with a three-dimensional model that took into account xenon and thermal-hydraulic feedback. Load-following and steady-state conditions were analyzed and compared with vendor results. For a PWR utilizing a minimum of control rod movement, a one-dimensional model was used.

The second category is the calculation of reactivity worths. Control rod and bank worths were calculated for a PWR using a three-dimensional core representation and static calculations. The time-dependent reactivity inserted by control rods during a scram was studied for a boiling water reactor (BWR). This was done using a two-dimensional, cylindrical geometry neutron kinetics code which included thermal-hydraulic feedback. The effects of different physical parameters such as inlet temperature, pressure, flow rate, insertion time, and initial power distribution and control rod configuration were studied. Various approximations were considered by looking at the effect of delayed neutrons, time dependent voids, and the definitions used for reactivity.

The third category of problem is in the interpretation of reactor measurements. Calculations were done to study the response of incore instrumentation in a BWR where certain problems had been encountered. In particular, the effect of detector movement and changes in void distributions were studied. Studies of the use of excore detectors in a PWR were also made.

Plant Transients

Studies of Anticipated Transients Without Scram (ATWS), steam line break, and other transients for pressurized and boiling water reactors have been carried out in cooperation with NRC personnel. For the calculations by BNL and NRC, a number of modifications have been incorporated in the RELAP3 code. The modified version is known as RELAP3B and serves as the standard regulatory tool for ATWS and other plant transients. Among others, these modifications include programming for steam generators, modification of steam table representation, relief valves, reactivity feedback, etc.

Plant descriptions have been furnished in terms suitable for code input as steady state representations to provide the basis for transient calculations.

Frequent consultations are held with NRC staff for interpreting the results of computer studies and for defining code and data modifications.

BNL has participated in calculations of sample problems so that the applicants' methods and results can be compared with each other and with those developed by BNL for the Nuclear Regulatory Commission.

Containment System Integrity

BNL has recently been given responsibility for providing technical support to NRC in the area of containment system integrity. This support consists basically of review of vendors' methods for predicting loads on containment structures, as well as general consulting on fluid mechanical aspects of containment-related phenomena. The designs that have been reviewed to date incorporate the pool type pressure suppression systems. In these systems, in the extremely unlikely event of steam line leakage, pressure within the containment structure is kept at a safe level by ducting the steam into a large pool of water where it condenses. In the early phases of this transient, the fluid entering the pool is a mixture of steam and air. The noncondensible nature of air results in a displacement of water in the pool. Associated with this displacement are certain loads on the pool walls and structural components within and above the pool.

The fluid mechanics associated with these phenomena are quite complex and not amenable to accurate analytical solutions, although simplified mathematical models have been used to obtain approximate answers. Fortunately, the problem lends itself readily to experimental simulation with small-scale models. By matching the necessary scaling parameters, the phenomena that would occur in a full-scale containment can be duplicated on a small scale. By appropriate scaling laws the full-scale pool velocities, pressures, and forces are readily obtainable from the test data. BNL has conducted in-depth reviews of the scaling laws and the experimental methods used in various test programs to obtain the hydrodynamic loading parameters.

Another related problem is the safety/relief valve actuation. This is a normal but infrequent event in which high-pressure steam is ducted into the pressure suppression pool, where the steam condenses. Here again, the first fluid entering the pool will be the air initially in the pipe. In this case, the amount of air is small, but at a high pres-

sure. The air bubble, once formed, continues to osscillate in size, resulting in a periodic pressure loading on the pool walls. BNL has reviewed the methods used to predict the full-scale loading conditions from test data.

Advanced Code Development

Nuclear power plants are licensed on the basis of criteria, a number of which involve the computer-predicted plant behavior during transients caused by hypothetical accidents. Of primary interest are the highly unlikely Loss of Coolant Accident (LOCA) and the ATWS. The former is postulated to be caused by the break of a major pipe in the primary coolant circuit and leads to a rise in temperature of the fuel cladding. The licensing criteria require that, following a LOCA transient, the maximum fuel cladding temperature remains below a prescribed safety limit. The ATWS accident could be induced by the unlikely simultaneous failure of turbine and control systems for the reactor shutdown. This transient leads to a rise in plant pressure, which must remain below a prescribed safety limit.

An advanced computer code for the prediction of accident-induced, thermo-hydraulic transients in reactor systems is being developed. The advanced code is expected to distinguish itself from currently existing codes by satisfying all of the following six objectives. The code must (1) account for thermodynamic non-equilibrium between vapor and liquid phases, (2) account for unequal phase velocities, (3) account for axial variations of the transient power generation in the reactor core, (4) predict also the initial steady state of the hydraulic system, (5) accommodate individual reactor system component modeling, and (6) have modular structure to facilitate continued updating of component modeling, material descriptions, and numerical techniques.

As a result of process modeling, the critical (choked) flow of the two-phase mixture of liquid water and water vapor has been described. Component modeling has led to preliminary descriptions of the thermohydraulic transients in the pump, the reactor core, and some piping elements. System modeling led to an efficient algorithm for the prediction of the initial steady state of the entire hydraulic system and to the formulations for the transient system balance equations. Several algorithms for the solution of ordinary and partial differential equations have been developed, or implemented, and employed to solve the coupled set of four conservation equations that model the non-equilibrium, inhomogeneous flow of two-phase mixtures. Efficient material descriptions for water and for structural materials have been implemented.

Fast Reactor Safety Evaluation

This activity is designed to provide analytical support to the Division of Project Management, Office of Nuclear Reactor Regulation (REG) of the Nuclear Regulatory Commission (NRC) in the field of fast reactor safety. The basic program is divided into the following five areas:

I. Accident Initiation Analysis.
II. Disrupted Core Analysis.
III. Post-Accident Heat Removal Analysis.
IV. Plant Dynamics and Reliability Analysis.
V. Fast Reactor Physics.

Task I is concerned with determining a best estimate of the initiating phase of hypothetical core-disruptive accidents in liquid metal fast breeder reactors (LMFBRs). Primary emphasis is placed on the initiation phase of transient overpower (TOP) accidents, particularly for the Clinch River Breeder Reactor (CRBR). The two central areas of investigation are fuel-pin failure dynamics and post-failure fuel and coolant motion (fuel plateout/plugging). During FY 1976, calculations of the initiating phase of TOP accidents under various core conditions and ramp rate in the CRBR were made using the SAS3A computer code. Progress was made in evaluating the potential for fuel plateout and plugging under TOP conditions and in defining fuel failure mechanisms for various core conditions and ramp rates.

Task II is concerned with the analysis of a disrupted core as a result of a loss-of-flow (LOF) or TOP accident in an LMFBR. The two areas of major concern are the dynamics of boiling pools and the potential for criticality of disrupted core configurations. For the LOF accident in the CRBR, scoping calculations were performed with the SAS3A code under various assumptions concerning fuel axial expansion reactivity feedback, clad relocation, and fuel slumping. In order to determine the possible escape routes for materials from a disrupted core, a model for freezing of molten fuel in an open channel has been developed.

Task III investigates the behavior of the fast reactor after initial neutronic shutdown following core disruptive accidents. A major effort concerns determination of the post-accident heat removal

(PAHR) problems for a spectrum of TOP accidents (ramp rates and burn-up histories) and LOF accidents for the CRBR. In order to identify the initial conditions for PAHR, analyses of the dynamics of molten fuel relocation above and below the core were performed. Some specific phenomena considered were the penetration of a fuel-steel jet into the upper sodium plenum and the rate of fuel and steel solidification within the cylindrical coolant paths below the core.

Task IV is concerned with the evaluation of LMFBR plant dynamics and reliability analysis. Major efforts involve the transient response of the reactor to a pipe break in the primary piping and the long-term decay heat removal under natural convection conditions. Reliability analysis of safety systems is being pursued, with emphasis on the development of analytical methods for the calculation of the reliability and availability of complex reactor plant systems.

Pipe rupture accident analysis has been carried out for the CRBR with the DEMO computer code. The thermal transient response of the reactor core was calculated under various conditions of reactor operation. Reliability analyses included assessments of the CRBR reliability programs for the shutdown systems, decay heat removal system, and piping integrity.

Task V concerns itself with the start of a reactor physics effort. This effort will have two overall goals: (1) to prepare the necessary reactor physics input for systems and accident codes, and (2) to analyze meltdown and vapor explosion critical experiments being carried out. The first step to be carried out on this effort will be the identification and acquisition of the necessary computer codes. The necessary cross-section libraries will also be acquired.

LMFBR System Transient Code Development

The major object of this activity is to develop a computer code that will simulate the response of a liquid metal fast breeder reactor (LMFBR) plant under postulated off-normal or accident conditions. Two of the hypothetical plant conditions that this program is designed to model are:

1) a major rupture in the primary heat transport system, and

2) long-term after-heat removal in the absence of forced circulation.

The potential degree of damage to the plant depends, of course, on the accident scenario. For example, in the event of a postulated massive pipe rupture at the "worst" location, there may exist a possibility of partial meltdown of the reactor core. In the case of loss of forced circulation, which might be due, for instance, to a loss of all circulating pump power, natural convection alone may not be sufficient to dissipate the after-heat satisfactorily. If it is not, there may again be a possibility of partial meltdown of the core. It is, therefore, important to take into consideration all of the phenomena that may be encountered during these transients.

Work on the development of a computer code to model these plant transients was begun. This code is designated as SSC (Super System Code). It models reactor system components in sufficient detail so that all of the pertinent phenomena, such as coolant stagnation, flow reversal, or boiling in the core, are adequately represented. On the other hand, in order to make it practical to use the code for large numbers of sensitivity studies, care is being given to the computer execution time and storage requirements.

A number of modeling decisions have been made. For example, it has been decided to represent the entire plant with no more than two sets of parallel loops. The time-dependent response of the reactor will be calculated from a set of pre-accident, steady-state operating conditions determined by the "initialization" module of the code from input parameters supplied by the code user. Work on the "initialization" module is almost complete and several time-dependent models have been developed. A preliminary version of the SSC code is expected to be ready in 1977.

The first working version of the code, SSC-LOOP, is being tailored for the current U.S. design of LMFBRs. This design employs the "loop" concept, as in the design of the Clinch River Breeder Reactor Plant (CRBRP). After the release of SSC-LOOP, a version of the code will be prepared to simulate "pool" type plants, such as the Phenix reactor. The initial versions of the code will be improved as parts of the computer models are validated against experiments and through sensitivity studies.

High Temperature Gas-Cooled Reactor Safety Evaluation

During 1974 the reactor safety studies were expanded to provide an independent capability for NRC for the overall safety assessment of the high

temperature gas-cooled reactor (HTGR) type and specific designs of this reactor.

The HTGR is a thermal reactor with an oxide or carbide fuel incorporated in a graphite core cooled by helium. Heat is removed from the primary helium coolant in steam generators. The core and the entire primary coolant system, including helium circulators and steam generators, are located within a prestressed concrete reactor vessel (PCRV). In the larger HTGR's, the PCRV is a multicavity vessel with a steel liner. The normal helium operating temperature and pressure at the core outlet are ~760°C and ~50 kg/cm^2. Since the HTGR differs radically from light water reactors in many ways, e.g., fuel cladding, moderator, coolant, reactor vessel, etc., safety assessment problems differ considerably from those for light water reactors.

Emphasis is placed on the public safety aspects of normal and accident conditions. The related subjects of long term reliability and failure modes arising during long term operation are included. A special aim of the program is to provide assistance to the Office of Nuclear Reactor Regulation in its evaluation of safety problems associated with this reactor type.

Structural Analysis

During the past few years a number of selected structural analyses have been performed for the NRC and its Reactor Safety Research Division (RSR). Numerous elastic and inelastic computer codes have been developed and applied to the static and dynamic analysis of structures and piping systems. Analyses were done for steam generator tubes, magnetic fusion reactor blanket and magnet systems, and components and systems of both the LMFBR and the HTGR. In two cases, the steam generator tubing and the piping systems, an entire program has been devoted to the subject. Work in this general area is expanding to include the technical management and analysis of materials testing activities at both Brookhaven and selected subcontractors' facilities.

NUCLEAR MATERIALS SAFEGUARDS

The function of the Technical Support Organization (TSO) is to provide technical assistance to both NRC and ERDA in developing improved safeguards policies regarding highly enriched uranium or plutonium. Either of these materials might be stolen, or diverted, to fabricate a nuclear weapon; in addition, plutonium or other radioactive byproducts of nuclear energy might become material for radiological threats to society.

In 1975, TSO advised the NRC on how it might compose a statement of its safeguards objectives. It also prepared a report on how the social as well as economic costs of safeguards measures might be evaluated. With the help of subcontractors, TSO analyzed the technical advantages and the societal costs that might result from "spiking" nuclear materials with various levels of radioactivity. The conclusion reached in this study was that the risks involved would not be compensated by any potential increase in protection that might be realized. The vulnerability of nuclear material records systems to falsification for the purpose of covering diversion at nuclear material fabrication sites was studied.

Technical assistance was also provided to ERDA in several areas. The safeguards implications of breeder reactors were analyzed for the Environmental Impact Statement on LMFBR's. Similar assistance was provided with respect to nuclear fuel reprocessing plants, plutonium fabrication plants, and other facilities that ERDA is considering for construction.

A computer model to test the response of ERDA facilities to attack by armed terrorists was developed. The model is portable and interactive so that it can be taken to any nuclear facility, and used in place, with local people participating.

Several of the current assignments of TSO are: (1) assist the International Atomic Energy Agency (IAEA), on behalf of ERDA and the U.S. Arms Control and Disarmament Agency, in determining how to apply IAEA safeguards to U.S. nuclear facilities, including how to enhance the credibility of IAEA inspections; (2) review the nuclear material control and accounting regulations, applied to the private nuclear power industry by NRC, to identify areas of weakness or over-regulation; (3) conduct an independent assay, jointly with a counterpart group at Los Alamos Scientific Laboratory, of the plutonium remaining in the Kerr-McGee nuclear fuel fabrication plant in Oklahoma, which has been shut down and cleaned out; (4) provide technical assistance to ERDA and other Government Agencies that will contribute to a decision as to how to monitor the processing of spent nuclear fuel from foreign power reactors for which fuel is supplied by the United States.

NATIONAL NEUTRON CROSS SECTION CENTER

A revised version of the national nuclear reference data library, ENDF/8-IV was issued in 1974. This revision incorporated new measurements performed and published since the formulation and issuance of ENDF/8 in 1972. This library has improved the accuracy with which nuclear criticality and decay heat after shutdown can be calculated. It was assembled with the cooperation of government laboratories, universities, and private industry and contains all the nuclear technology needed by nuclear power reactor designers.

Library revisions and extensions are in progress for release in January 1978.

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ACCELERATOR DEPARTMENT

SUPERCONDUCTING POWER TRANSMISSION

One of the long-standing problems in the energy field which is becoming more serious is that of transmission of electric power, especially when large amounts of power must be handled in congested areas. The usual remedy of increasing the voltage on the line is running into trouble. Higher voltages on overhead lines require taller towers, greater spacing between conductors, and correspondingly wider rights-of-way. The towers are objected to vigorously on aesthetic and other grounds, and the rights-of-way are becoming very expensive.

The obvious solution is to use buried cable which would need a right-of-way only a few meters wide. But buried cable has a severely limited power handling capability; the voltage cannot be very high because of insulation problems, and the current must be kept low to avoid heating which would damage the insulation. The resistive component of the heating can be eliminated by making the cable superconductive.

This problem has been studied for several years by a group of scientists and engineers of the Department of Applied Science and the Accelerator Department, under the administration of the latter.

The objective of the program is to develop an underground superconducting power transmission system which is economical and technically attractive to the utility industry. The system would be capable of carrying very large blocks of electric power, thus enabling it to supplant overhead lines in urban and suburban areas and regions of natural beauty. A study of new methods of power transmission, conducted for the National Science Foundation, was completed at the end of 1971. It concluded that superconducting ac cables appeared technically and economically attractive for circuit loads above 2000 MVA.

This technical choice determined the course of the development program at Brookhaven. The choice of a superconductor appeared to be Nb_3Sn, but measurements of hysteretic loss showed this loss could be a factor of 5 to 10 times larger than other heat loads on the refrigerator. A major goal of the early work was to reduce this loss; this has been achieved successfully. Nb_3Sn designed at BNL for this application has losses about the same as niobium but much better current-carrying ability. It was found at BNL that the intrinsic loss characteristics of many Nb_3Sn samples had been masked by losses arising in the solder and cladding used to manufacture the tape. Once these parasitic effects are removed Nb_3Sn manufactured by several methods will possess low losses if certain metallurgical conditions on the grain size and surface roughness are met. A method of manufacture has been developed at BNL to achieve these conditions. The theory has been extended to include temperature dependence and good agreement has been obtained between calculated and measured results. Once the cladding is removed from a superconductor the quench current is usually reduced due to the onset of flux-jumping at lower fields. How to minimize losses without sacrificing current-carrying ability is a problem now being studied. Tapes possessing the desirable properties have now been made commercially using the techniques developed at BNL.

The insulation of a flexible superconducting cable must permit bending during installation and must withstand a high operating electrical stress for many years without deterioration. During the

past two years many materials have been examined for suitability in this service and apparatus has been constructed to determine mechanical properties and breakdown stresses of plastic tapes. A few materials have demonstrated acceptable breakdown values, but a sample which has all the desirable properties has yet to be made. Work has started on the mechanical problems of designing the composite cable so that it is not destroyed on cooldown. A trial cable about 457 m long was made to BNL specifications by a commercial cable lapping company. This cable incorporated three prime candidates for the electrical insulation. Sections about 20 meters long are now under test in the Laboratory.

Although there is a natural tendency to concentrate somewhat myopically on the problems of cable design when developing a new electrical transmission system, the fact is that the design of the cryogenic equipment is likely to pose equal, or greater, problems. The low temperature envelope containing the cables in a thermally-insulated environment is likely to cost more than any other single item in a superconducting transmission system. An active development program is now underway concerned with this class of equipment. Four concepts for the design of the envelope have been studied. One is a completely flexible cryostat manufactured commercially in West Germany.

Another cryostat has been ordered from a U.S. cryogenic equipment company, and two have been made at BNL. To evaluate these designs a laboratory has been created at BNL with a small supercritical helium refrigerator. Once evaluated as cryogenic components the cryostats have been used as enclosures for cable tests. The second BNL cryostat is the prototype of an enclosure which is to be erected as part of an outdoor test facility. The refrigerator for the facility is now being assembled at BNL. It is rated at 500 W at 6 K and produces supercritical helium at about 15 atmospheres. A screw compressor and gas turbine expanders are used in order to provide long-term reliability.

The joint investigation with the Long Island Lighting Company (LILCO) continues. The basis of this investigation is a 345 kV transmission corridor about 65 km long with a 4800 MVA capacity. The cost analysis and most engineering designs for this requirement were made by outside consultants. The results appear encouraging, with the superconducting designs significantly less expensive than a competing conventional system and, in the best case, only a factor of 2 more expensive than a 345 kV overhead system. A study of a 350 mile transmission system was also completed, although this is not seen as a typical application. The technical problems of designing a transmission line this long are formidable. The superconducting design appears to have a performance as good as a high voltage overhead system but the cost is about 3 times as high.

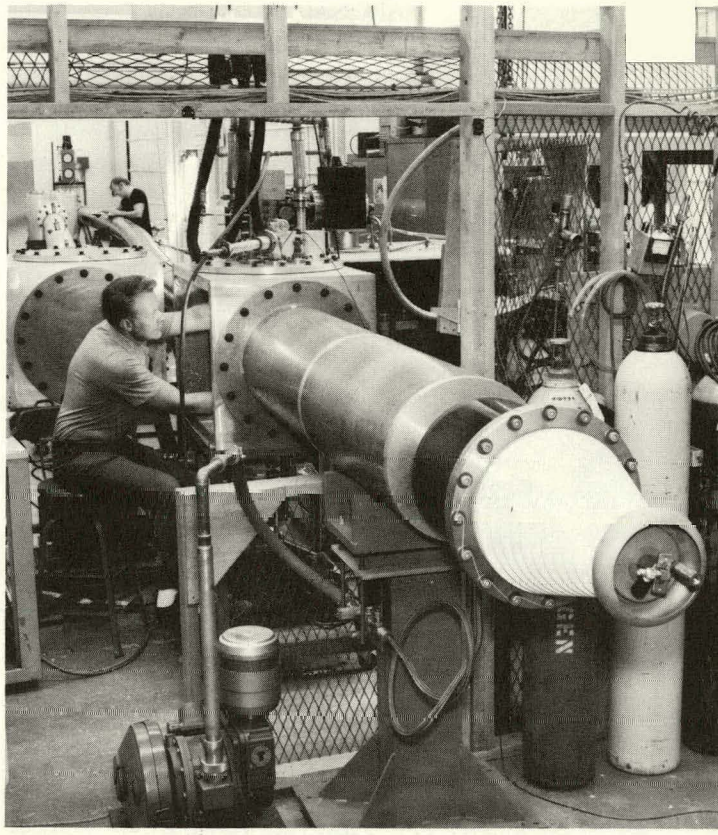

Figure 9. Electrical insulation is evaluated by placing the cable in a 21-m cryogenic enclosure. The electrical connections to the cable are made using the high-voltage bushing seen in the photograph.

The project has made significant contributions to the U.S.–U.S.S.R. exchange in Superconducting Transmission and has served as host for several Russian visits. Experts from the project have visited the U.S.S.R. This year Congress voted the funds to purchase a refrigerator to be loaned to the U.S.S.R. to cool a demonstration 1 km superconducting line. The project staff has served as technical experts for this purchase which will be made by BNL on behalf of ERDA.

SUPPORT ACTIVITIES

APPLIED MATHEMATICS DEPARTMENT

INTRODUCTION

The Applied Mathematics Department performs the dual role of conducting mathematical and computer sciences research and providing computational services to the Laboratory's scientific activities. The environment at BNL is well suited to research in mathematics and computer science because the overall research program of the Laboratory embraces a broad spectrum of activities with widely varying mathematical and computational requirements. Because of the close relationship between the mathematical and computer sciences and other scientific disciplines, the research conducted by the department has an impact on many other research activities. Hence, while the work done is directed, in particular, toward the advancement of these two fields, it is carried out with a concern for the needs of scientific research in general. In its service role, the department operates the large scale BNL Central Scientific Computing Facility which supports the overall research program of the Laboratory, and provides time to federally funded research activities at other institutions. Related services, such as applications programming, are provided also.

MATHEMATICAL SCIENCE RESEARCH

The broad basic goal of the mathematical science research at BNL is the investigation of new or improved mathematical techniques for the formulation, analysis, and solution of the highly complex mathematical problems occurring in scientific research. Most of the mathematics research at BNL makes extensive use of high speed computers for its effective implementation. There is also considerable interaction with other departments at BNL as well as other institutions.

Major areas of current concern include numerical procedures for solving differential equations, mathematical programming, and mathematical

statistics. Analytical and approximation techniques, mathematical modeling, and other advanced computer-based procedures are also being addressed. A few representative samples of this research activity are given below.

Numerical Solution of Differential Equations

A very large class of problems occurring in scientific research is dependent on the solution of extremely complicated mathematical problems, often formulated in terms of differential equations. Due to the complexity of those problems, the best that can usually be hoped for are reliable, efficient numerical algorithms that yield good approximations to the exact solutions with the aid of high speed computers. At BNL, a number of different finite element, finite difference, and variational techniques have been analyzed and applied to specific problems.

The finite element method is one of the most powerful and widely used tools for approximating the solutions of differential equations that occur in diverse areas of research, such as structural mechanics, reactor safety, and fluid dynamics. It is important to be able to analyze mathematically the different types of finite element methods available in order to apply them efficiently. Research conducted at BNL has been concerned with the question of determining the rate of convergence of various finite element approximations to the exact solution.

In particular, it was proved for a class of linear problems that the optimal rate of convergence holds in the sense of uniform pointwise convergence. The proof of these optimal uniform estimates represented the verification of a long standing conjecture that had defied the attempts of a distinguished list of researchers for many years. In addition to this, several other interesting theoretical results concerning the finite element method were obtained.

A finite element conference was sponsored by the Applied Mathematics Department at BNL in March 1976, bringing together the leading mathematicians in the field to discuss recent results and new areas of investigation.

Another variational technique of widespread application is the method of moments. This method formed the basis for an algorithm developed in collaboration with the Accelerator Department at BNL, relevant to Brookhaven's rf particle separator. This work was successfully completed with the development of a computer program for calculating the dispersion curves and electromagnetic fields in periodic, iris-loaded waveguides. The method was then generalized to more complicated physical and mathematical problems.

There was also a collaboration with the Atmospheric Sciences Division of the Department of Applied Science. The goal of this work is to produce reliable and efficient models of the proliferation of pollutants in the atmosphere. The basic mathematical problems involved are numerical solutions of the diffusion – advection equation (with small diffusion) and determination of statistical properties of solutions of stochastic partial differential equations. Various different numerical techniques were considered and convergence proofs were given in several cases.

Finally, work is in progress on the solution of the Helmholtz (or reduced wave) equation, subject to certain boundary conditions and radiation conditions at infinity. This is the model employed in a wide variety of scattering and diffraction problems. Consequently, its solution is of importance in many areas of research, such as acoustics and microwave physics. Research conducted at BNL has aimed at treating such problems both computationally and analytically. It has been determined that standard finite element and finite difference methods are successful when the frequency is not too high. New computational procedures are now being applied for high frequencies.

Mathematical Programming

Mathematical programming models are widely used in various areas of research, such as energy systems research. The ability to solve larger problems better can extend the scope of such research to include models of greater detail and accuracy. The mathematical programming research at BNL is concerned with the development, implementation, and experimental investigation of efficient computational techniques for various types of optimization problems of practical importance. Several examples of the application of this methodology were seen at an open conference on energy-related modeling and data base management, held jointly by the Departments of Applied Mathematics and Applied Science at BNL in the Spring of 1975.

An important part of this research deals with large scale linear programming models. Most op-

timization problems of the resource allocation and production planning type are highly structured. The two most common structures are staircase and block-angular. Algorithms that exploit the problem structure were developed at BNL to handle large scale problems more efficiently than general methods. To cite one specific example, a dynamic energy model developed at the Harvard Energy Policy Center was solved at BNL using the staircase algorithm. Various computational experiments verified efficiency improvement of up to 50% over traditional methods.

A second question being treated by this research effort is concerned with the development of efficient algorithms for a dynamic model for traffic control over a network in which congestion is treated explicitly in the flow equations. The results are relevant to environmental and fuel conservation aspects in transportation studies. A specific model for dynamic traffic assignment was studied and a very efficient hybrid algorithm was developed for this problem.

The final aspect of the mathematical programming research deals with nonlinear optimization problems. The goal is to develop, adapt, and refine such methods according to current needs in energy research. Work was initiated to study the class of generalized reduced gradient methods for nonlinear programming problems. In addition, a series of seminars on nonlinear optimization in energy related research was begun in the Spring of 1976 in an effort to expand the nonlinear programming research at BNL. Experts in appropriate areas were invited to give survey lectures and possibly engage in consultation or collaboration on specific research problems.

Mathematical Statistics

The major concentration of research in statistics at BNL lies in the three areas of fault tree analysis, "robust procedures,"* and statistical inference with the boundary crossing approach. Work was begun on applying the fault tree method to the development of a technique for fast identification of failure sources in systems such as nuclear power plants. The results on robust procedures have been applied to statistical problems related to a BNL study on the environmental and health effects of industrialization.

*A "robust procedure" is a statistical procedure that guarantees a valid conclusion even when a certain limited departure between the assumed and the true underlying models is allowed.

In connection with the fault tree method, efforts were initiated to find a procedure that simplifies a fault tree without violating its stochastic structure. The question of error propagation in a fault tree was also studied. In addition to the statistical aspect of the fault tree methodology, an investigation was made into pipe bursting problems and useful results on burst probability were obtained.

The research on robust procedures treated problems of estimation, hypothesis testing, regression, and time series. An exact and robust test for contaminated data from an exponential underlying model was obtained. Furthermore, a general estimation method called the Linear Maximum-Likelihood method was developed at BNL. It is believed that this method will provide an answer to an important regression problem being studied in a project on adaptive robust statistical procedures.

The primary aim of the research on statistical inference with the boundary crossing approach is to investigate the probabilistic structure of boundary crossings and its usefulness for inference. A new method was developed at BNL for evaluating boundary crossing probabilities. Distributional properties of random variables representing the times of first and last crossings of sample sums over boundaries, as well as the total number of such crossings, were investigated. Interesting and useful results were obtained for linear boundaries and several types of nonlinear boundaries. An inference method in hypothesis testing was also developed, based on the number of times a sample sum crosses a linear boundary.

Other Research Activities

In addition to the above-mentioned examples, research was also conducted in several other areas during this time period. These include:

1. Statistical mechanics of phase transitions (with applications to material research),
2. Mathematical approximation theory (with emphasis on Padé approximants),
3. Reconstruction of multidimensional structures from their projections,
4. Planar graph theory, and
5. Theory of partial differential equations.

COMPUTER SCIENCE

Computer science research at Brookhaven is concerned with the most efficient and effective use of computers for scientific research. With the in-

creasing availability of large scale computers to the scientific research community, it has become apparent that better techniques for the sharing of computer resources and exchange and retrieval of scientific data are needed. The major part of the computer science research program has addressed problems in these areas; other areas of study have been the automation of digital system design and computer systems modeling.

In December 1975, Brookhaven joined the ARPANET, an international computer network. Access to this network is being used to study the advantages (and disadvantages) that a large network of computers offers to scientific research efforts.

Because the access to the network is relatively new only small experiments in network usage have been performed. The following is an example of the use made of the network both for information handling and access to unique computer facilities: A large program assembly listing of a program in use at BNL, but whose source code was available only at a Stanford Research Institute computer, was sent over the network to Lawrence Berkeley Laboratory where it was put on microfiche and mailed to BNL.

A large computer network also allows access to computer resources not available at an investigator's home institution. For example, the network has been used for access to MACSYMA, a PDP-10 based symbolic algebra system available at MIT. This system was used to provide a complete analysis of a queuing network in about one-half hour, whereas about five hours of hand calculation had previously been unsuccessful in producing a solution. As another example, network access to an IBM computer system is being used to check the "portability" of a program being developed on a CDC computer system.

Data Base Management

A study of types of sequentially organized machine generated data was initiated to study the problems of archiving and disseminating data. A formal description was constructed leading to an enhanced understanding of the nature of many forms of sequentially organized data.

At present, it is believed that placing a machine interpretable physical logical description (PLD) in front of the stored data (without reorganization) is of great use in the archiving, retrieving and disseminating of these data. The PLD will contain machine interpretable information concerning:

Figure 1. The central processor of the Cyber 70/76 computer system is being checked as part of preventive maintenance which is performed daily. This unit is the heart of the system and contains the highly complex, very high speed electronic circuitry which performs massive computations.

(I) the organization, collecting, and disseminating of the recorded data,

(II) the physical dimensions and accuracy of the recorded data,

(III) bibliographic information on reports dealing with the data, and

(IV) the formats of the physical machine recorded data.

Under the present mode of operation, recorded data reside at computing centers, information on the accuracy and meaning of the data resides in reports placed in archives and libraries, and the format description resides in the programs used to produce the data for the report.

A PLD was designed and used to describe several diverse types of data; e.g., meteorological data collected at BNL, the census bureau's dissemination tapes, the museum computer network's data input types to their DBMS GRIPHOS, and personnel record tapes described in textbooks on data processing.

Based on this PLD a data manipulation language (DML) has been specified, containing eight modules upon which a DBMS can be built to organize, retrieve, and disseminate machine constructed sequential data.

Digital Design Automation

A unified digital design automation system has been conceived and developed within this project. With this tool, entire digital systems can be synthesized, simulated, and documented at any level of detail. MODEL is a digital simulation language containing features which facilitate description of networks implemented in LSI technology. LINDA is a behavior specification language and algorithm for synthesizing designs. The system includes a graphical output documentation algorithm. The system is able to solve problems of firmware synthesis and can simulate firmware and software modules as well as network, making it more useful for the analysis of entire digital systems. A read-only memory device simulation capability was added. Facilities were introduced for modeling Petri nets which are graphical constructs that can represent the interaction of software modules. A modified Petri node was defined, and descriptors and processors for handling modified Petri net constructs were integrated into MODEL as well. The characteristics of modified Petri nets were explored, with particular attention to the properties of "liveness" and "safeness." In these important areas, modified nets were found to have identical behavior to that of formal Petri nets, implying that MODEL simulation is a reliable and valuable tool for software modeling.

Central Scientific Computing Facility

The Central Scientific Computing Facility (CSCF) of the Laboratory is operated by the Applied Mathematics Department and is housed in a specially designed computer wing. The facility provides large-scale, general-purpose computational support to the Laboratory's research program and performs the bulk of BNL's scientific data processing. Universities and other outside organizations engaged in federally supported research also utilize the CSCF.

On weekdays, the CSCF has been open for fifteen hours of full production and three hours of prescheduled production (the latter with reduced staffing); the remaining six hours have been devoted to production dry-up prior to preventive maintenance, performance of preventive maintenance, and production start-up following preventive maintenance. During Saturdays and Sundays, the facility has been available for eleven hours for full production, and thirteen hours for prescheduled production.

Current Hardware Configuration

The CSCF is equipped with a Control Data Corporation (CDC) Cyber 70/76 computer and two CDC 6600 computers sharing one and one-half million words of extended core storage. The CDC 6600 computers, besides acting as front ends to the Cyber 70/76, provide the users with both batch processing and interactive facilities. The INTERCOM system allows remote job entry, interactive file manipulation, and interactive computing both from directly connected terminals and over common-carrier lines. Thus, the CSCF resources, especially the extremely powerful Cyber

Figure 2. A view into the control console area of the CSCF from which computer operators interact with the CDC Cyber 70/76 and the two CDC 6600 computers. In the background, operators are mounting tapes containing data to be used in computations.

70/76, are made available to any authorized user having access to a terminal and a telephone. As a result the CSCF facilities are being used not only by BNL researchers, but also by groups at other ERDA laboratories and in other Federal agencies who normally would not have such a powerful computer complex at their disposal.

BROOKNET, a 12-million-bit/sec digital communication system, interconnects 17 remote on-site computers to the CDC 6600's. The computer-to-computer digital communications network enables the remotely located satellite computers, which handle data acquisition, graphical display, preprocessing, and other functions, to utilize on-line the greater computational capability of the CSCF computers. This system also allows remote computers access to the central data storage system and to the central input-output job queues.

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INSTRUMENTATION DIVISION

INTRODUCTION

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 ERDA. 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 contains two major service groups. The first provides repair service for the major types of instruments utilized by many scientists within the Laboratory; the second provides maintenance for the many small computer systems belonging to various Laboratory research groups.

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.

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; computer system applications for controlling and acquiring data from scientific exepriments; and application of nuclear techniques in medicine and other fields. Some of the more important recent results are described below.

PARTICLE DETECTORS

Lithium Transition Radiator and Xenon Detector System for Particle Identification at High Energies

New types of detectors for particle identification at high energies using the transition radiation effect have been developed and tested in collaboration with the BNL Physics Department and Yale University. One such system employing these detectors for discrimination between electrons and hadrons is the first large-scale transition radiation detector system to be used at the CERN Intersecting Storage Ring (ISR).

Transition radiation x rays are emitted by a fast charged particle passing through the interface between two media of differing dielectric constant. The x-ray intensity increases almost linearly with the particle Lorentz factor, γ. Lithium metal foils were used as radiators because of their high x-ray transmission property. The radiated x rays were detected with a multiwire proportional chamber filled with xenon. This Li-Xe system makes it possible to discriminate between particles of different mass even though the particles produce nearly equal amounts of ionization at these energies.

Transition x-ray yields were measured for high energy particles (e,π) by utilizing beams produced at the AGS and at Fermi National Accelerator Laboratory. The theoretical linear increase in x-ray intensity with particle γ was confirmed for pions in the momentum range 100-250 GeV/c. Also, the results for 50 GeV electrons ($\gamma = 10^5$) exhibited the theoretically predicted saturation phenomena. The experiments demonstrated that excellent electron-hadron discrimination could be achieved with only a few radiator-detector sets.

The first large-scale system of particle detectors employing the transition radiation effect includes a set of large area ($\sim 0.5 \times 1.2$ meters) chambers equipped with charge-division readout. This type of readout makes possible the unambiguous determination of pairs of coordinates for multiple particles traversing a single chamber. The readout electronics incorporate a unique new input circuit configuration which provides an inherently accurate sum of the signals from the two ends of a chamber wire and, thereby, a linear relationship between the output of the circuit and the particle position.

A position resolution of 0.4% of wire length and an electron-hadron discrimination ratio of ~ 19 were obtained for electrons (≈ 2 GeV/c) and protons (≈ 12 GeV/c) traversing the chambers at an angle 22.5° to the normal.

Delay Lines for Nuclear Particle Position Readout in Gaseous Detectors

The delay line method uses the difference between the arrival times of a locally induced signal at the two ends of the line to determine the initial position of the particle.

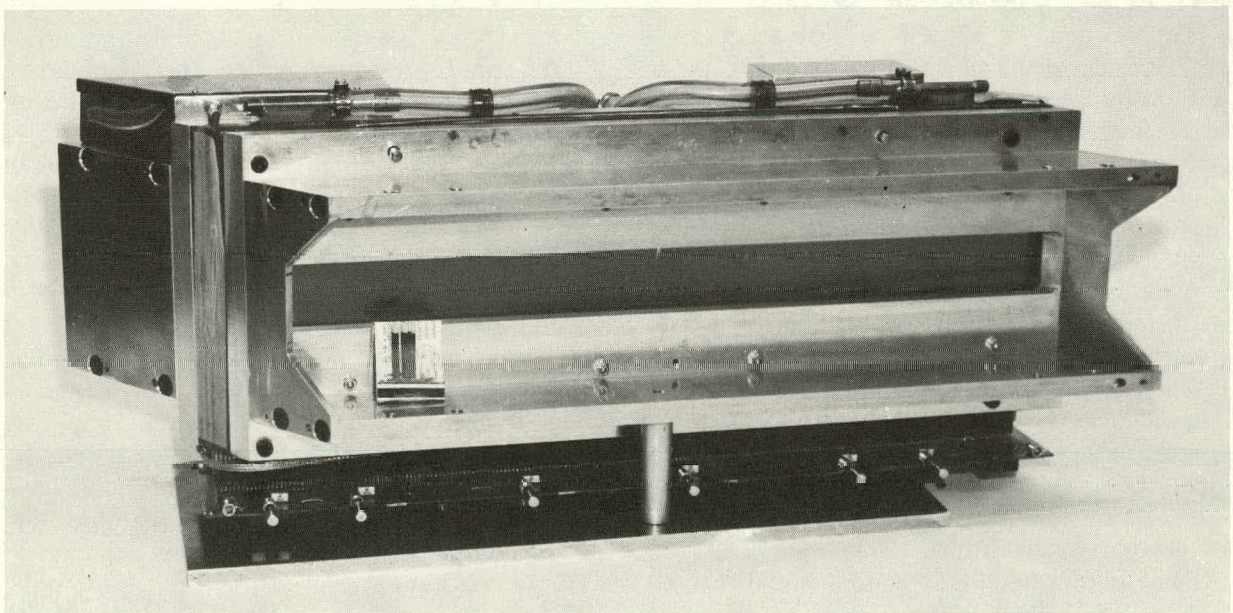
A new type of flat delay line has been developed which has a low propagation velocity and a very high delay to rise time ratio. This type of line can be constructed by printed circuit techniques and thus it can form the cathode plane of a proportional chamber. The design of the line is based on magnetic loops having a shifted periodic structure which yields a high inductance per unit length.

A second type of delay line studied consists of a flat coil wound around a strip of plastic with a narrow ground strip on one side. The geometry and hence the signal propagation velocity of these lines can be tailored to the specific proportional or drift chamber under consideration. Position readout along a chamber anode wire is obtained from the signal induced on the delay line through a high resistivity coating on the inside of the chamber window. This coating acts as an internal electrostatic cathode. In order to achieve precise time measurements with the small signals induced on this type of delay line, the preamplifiers at both ends of the line provide electronically cooled terminations. For example with a line having a propagation delay of 3.2 nsec/cm, a position resolution of 1mm was obtained for minimum ionizing incident particles, and 0.4 mm for 6 keV x-rays.

Multiwire Proportional Chamber as the Detector Element of a Focal Plane Magnetic Spectrometer

Two position-sensitive multiwire proportional chambers were developed for use in the high reso-

Fig. 1. Multiwire proportional chamber for the focal plane magnetic spectrometer. Particles enter the chamber through its window area (dark strip at center). The delay line for determining particle position is located at the bottom.



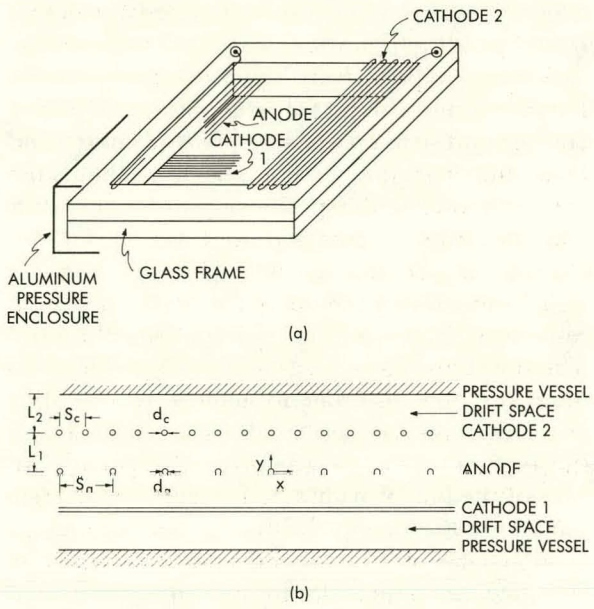


Fig. 2. (a) Schematic diagram of a position-sensitive neutron detector. Neutrons enter the chamber along the y direction. By detecting the charge induced on cathodes 1 and 2, the position at which a thermal neutron enters the chamber can be determined. (b) Parameters of the chamber. The interelectrode spacing, L_1, and drift space, L_2, are each 3.17 mm. The spacing between anode wires and cathode wires, S_a and S_c, is 2.54 and 1.27 mm, respectively. The anode is constructed of 0.02 mm diameter (d_a) stainless steel wire; the diameter of the cathode wire (d_c) is 0.1 mm.

lution focal plane magnetic spectrometer at the BNL Tandem Van de Graaff accelerator.

The first chamber (50 × 4 cm) utilizes an externally tapped delay line to read out its cathode with a spatial resolution of ~0.5 mm. Simultaneous measurement of differential energy loss (dE/dx) information from the chamber anode is possible, so that identification of particles with masses in the range of the proton to light and medium ions can be made.

A second chamber (75 × 2 cm) was built for the detection of heavier ions. This chamber is also position-sensitive and yields information on particle total energy, E, as well as dE/dx information. The chamber consists of two compartments with a single anode wire in each. A thin compartment yields the spatial position and dE/dx information. The second compartment is suffiently thick that the heavy ions stop in the chamber gas. The total ionization produced in this compartment is measured to obtain the particle total energy, E.

Position-Sensitive Neutron Detectors

One- and two-dimensional position-sensitive detectors for thermal neutrons have been developed for determination of the structure of proteins and cellular components in molecular biology. These detectors are based on a gas proportional counter using ^{3}He as the neutron-sensitive medium. At thermal neutron energies the neutron interacts with a ^{3}He nucleus to form a triton and proton, with the proton having a specific kinetic energy (574 keV). Because of the short range of the triton and proton, these particles ionize the detector gas in a small region close to the point of the initial interaction. The electrons liberated in the ionization process are multiplied in the high electric field region near an anode wire of the detector. An electronic readout system measures the position of the electrons collected at the anode. Position determination in either one or two linear dimensions is possible.

The two-dimensional detector now in operation has an active area of 18 × 18 cm with a spatial resolution of 3 mm and a detection efficiency of 70% at thermal neutron energies. The one-dimensional detector is one meter long, has a similar spatial resolution, and a detection efficiency of 75%. These detectors enable molecular biologists to determine the structures of samples that were impossible to investigate with previous neutron detection techniques.

Mixtures of Heavy Gases as Ionization Media for Detectors

The spatial resolution of detectors is limited by the range of interaction products in the detecting gas. A study has been made of some gas mixtures which are superior to argon in respect to range of interaction products. The study also seeks to identify gas mixtures which have low γ-ray cross sections. Such mixtures can be used to advantage in detectors for thermal neutrons. The ranges of 5.48 MeV α-particles in these mixtures have been measured; the suitability of some of the higher gaseous hydrocarbons for use in multiwire proportional chambers has been investigated. It appears that a range reduction by a factor of four over the range in argon can be achieved. Heavy gases have also been utilized in detectors for heavy ions. The reduced range obtained allows these detectors to be operated at lower pressures and thus to have thinner windows.

MAGNETOMETER FOR ISABELLE MAGNETIC MEASUREMENTS

The superconducting magnets for the proposed Intersecting Storage Accelerator (ISABELLE) must produce very precisely controlled time varying magnetic fields. The distortions in these fields as a function of time and space must be very accurately known. In association with the ISABELLE magnet group, a rotating coil magnetometer capable of measuring the average magnetic field to one part in 10^5 in less than one second has been developed. The magnetometer also detects and measures spatial harmonic distortion to an accuracy of one part in 10^6 of the main field. The magnetometer coil assembly is configured to provide sensitivity to specifically selected spatial harmonics and rejects unwanted terms by as much as a factor of 1000. A digital phase-sensitive detection technique provides additional selectivity so that a selected harmonic can be detected in the presence of a main field a million times more intense.

REMOTELY CONTROLLED REAL-TIME DATA COLLECTION SYSTEM FOR COASTAL OCEANOGRAPHY

A remotely controlled real-time data acquisition system (EDATS) for the measurement of physical oceanographic parameters at numerous unattended off-shore sites has been developed. The system was first deployed in July 1975 and has since been brought into routine operation.

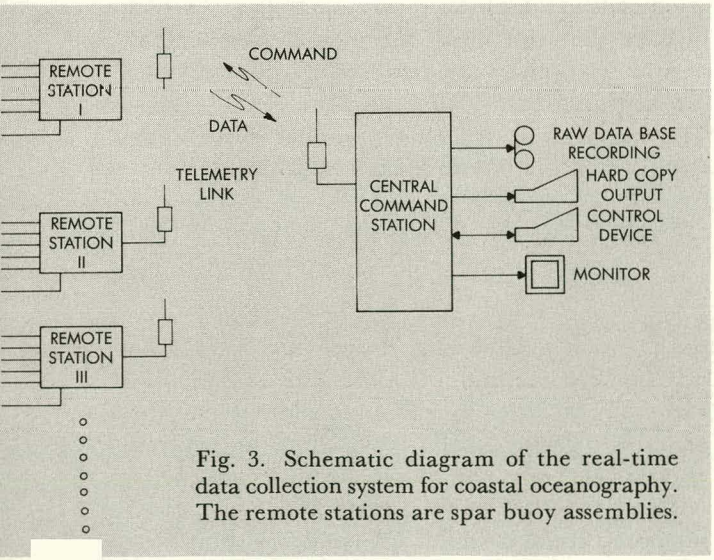


Fig. 3. Schematic diagram of the real-time data collection system for coastal oceanography. The remote stations are spar buoy assemblies.

This work was performed as part of the Coastal Boundary Layer Transect (COBOLT) experiment conducted jointly by the Department of Applied Science and the Instrumentation Division of BNL and personnel of the Woods Hole Oceanographic Institute.

A major difficulty in oceanographic experimentation is that it is generally impossible to repeat experiments for the purpose of verification of collected data because the environmental conditions prevailing during an experiment can seldom be duplicated. Therefore, a prime objective in the design of the system was to incorporate into the real-time measurement process all functions necessary to verify and correlate the incoming data.

The system is schematically represented in Fig. 3. It consists of:

(a) a mobile central command station installed in a trailer. This trailer is presently located on the Laboratory site at the base of the Meteorology tower;

(b) a set of remote stations located approximately 8-32 km off the south shore of Long Island in the Atlantic Ocean.

An oceanographic experiment is automatically controlled and monitored by programs which are executed in a computer forming part of the central command station.

Each remote station is mechanically constructed as a spar buoy assembly. Such an assembly includes a battery package, five sets of instrument packages, a data processor, and a radio transmitter/receiver and antenna. The remote station data processor may be viewed as a special-purpose computer which communicates with the central command station via two telemetry channels. The data processor performs the following functions:

(a) continuously collects data from the different types of instrument packages;

(b) verifies and reduces the collected data as much as possible in real time. This reduction decreases the amount of power required to transmit the data back to the command station;

(c) executes commands initiated by the computer program executing at the command station. The data processor, including its 256 word $\times$ 32 bit internal memory, has been constructed using low-power CMOS integrated circuits. Its average continuous power consumption is less than one watt.

Communication between the central command station and the remote stations is carried out via a request/response dialogue. Information tran-

mitted at the request phase includes the remote station address and the command code. Typical commands are:

(a) connect/disconnect power to instrument packages;

(b) start/stop collection interval;

(c) clear internal memory contents;

(d) select appropriate reference voltages for test and calibration of electronics.

The system has enjoyed an excellent reliability record since it was first deployed.

REACTOR EXPERIMENT CONTROL SYSTEM

A major system for control of and data collection from a set of laboratory experiments was placed in routine operation during the reporting period. This system, the Reactor Experiment Control Facility (RECF), is located at BNL's High Flux Beam Reactor. The system simultaneously controls triple-axis spectrometers for ten neutron and one x-ray diffraction experiments undertaken for molecular structure determinations. The system has a "finger" structure in which eleven small computers (or private processors), each supervising a single spectrometer system, communicate directly with a central or common node computer.

The primary objective determining the system architecture is to provide as much isolation between individual experiments as possible. A hardware or software failure occurring at one experiment must not affect any other experiment. This isolation is achieved by confining control operations, which tend to be complex and may often be modified, to a processor assigned to a single experiment. On the other hand, operations that can be assigned a fixed and rigid form (such as input/output operations to a peripheral device) are performed by the central processor upon receipt (via a high-speed communication link) of a request initiated by the private processor. This system architecture also has great economic advantages in that each private processor has access to an entire set of costly peripheral devices. It would be impossible to provide such a set for the exclusive use of each individual experiment.

A second design objective is ease of development of programs for the private processors. This objective is met by employing FORTRAN, a scientific computer-programming language familiar to many scientists, as the private processor language. The usual obstacle to using FORTRAN in a small computer, the great length of the resulting code, is surmounted by dividing the experiment control programs into sequentially executed parts (overlays) and storing these sets of program parts on a random access device connected to the central computer. The overlays are loaded into the memory of a private processor and executed in response to a request initiated by the private processor over the communication link. Thus the experimenter is relieved of the tedious job of writing and optimizing an assembly language code for experiment control.

Operation of the system during the reporting period has established the correctness of the choice of system architecture. The central computer has operated without error for as long as eight weeks (two reactor cycles). During this time, every experiment had contiuous access to the full set of services provided by the system. The amount of program code managed by the system has grown to the point that each experiment now has approximately 100,000 words of control and data acquisition code available to it.

At present, the operating system at the central computer is being extended so that more services can be provided by the node. One of these services, currently under development, is file management for files of experiment parameters.

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REACTOR DIVISION

INTRODUCTION

Two reactor facilities produce thermal neutrons which are used primarily in beam experiments of various types and secondarily for the irradiation of specimens. The High Flux Beam Reactor (HFBR) offers intense thermal neutron beams as well as irradiation facilities in which specimens may be exposed to various portions of the reactor neutron energy spectrum. The Medical Research Reactor (MRR) is no longer used primarily for medical purposes, but offers a flexible facility with moder-

ate neutron intensities which can easily accommodate a wide variety of experiments for any part of the laboratory. The research done by the various scientific departments with these reactors is described in the appropriate sections of this report.

HIGH FLUX BEAM REACTOR

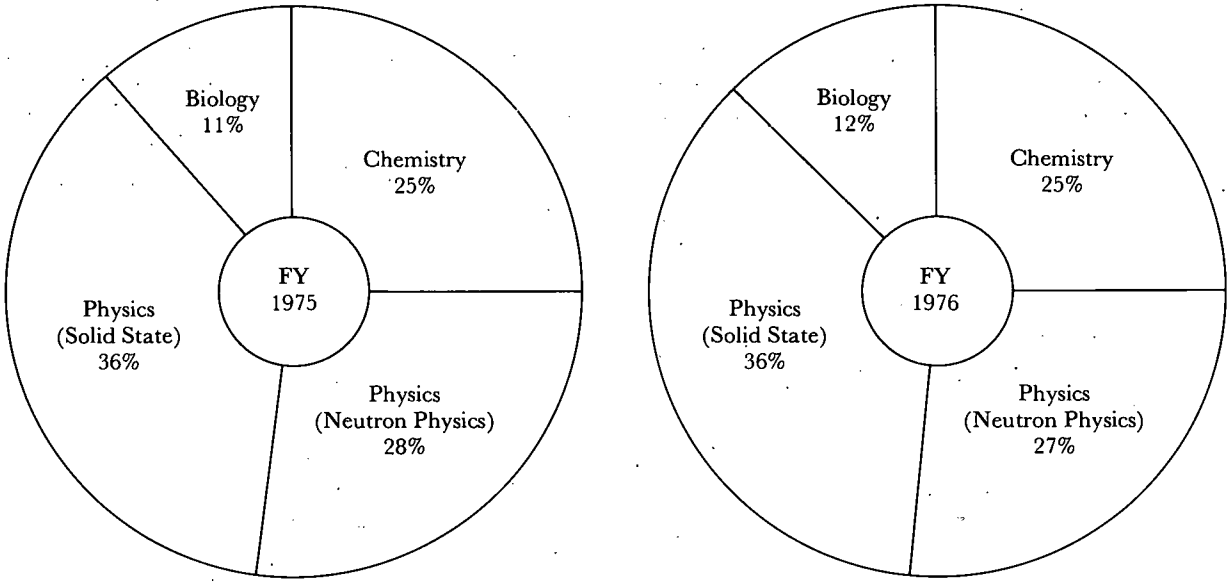
The High Flux Beam Reactor (HFBR) was operated during the past two years with an excellent reactor availability record. Significant unscheduled downtime was limited to three occasions, ranging from one to eight days. During this period, improvements to the in-core fuel management program were instituted, and reductions in personnel radiation exposures and environmental tritium releases were effected. Administratively, a Reactor Division quality assurance program was planned and instituted. The support of the HFBR by the various scientific departments is shown in Table I.

Fuel Management Program

In July 1975, a new in-core fuel management program was commenced to provide a more efficient utilization of HFBR fuel elements. The essential change was to abandon the fourteen element-two cycle fuel rotation scheme and institute a seven element-four cycle program, whereby only seven

Table I

Distribution of Support of HFBR Operations From the Scientific Programs



	Use charges			
	Fiscal 1975		Fiscal 1976	
	Amount, $	% of support	Amount, $	% of support
Physics Department				
Neutron Physics	520,800	28	502,200	27
Solid State Physics	669,600	36	669,600	36
Biology Department				
Biological Research	204,600	11	223,200	12
Chemistry Department				
Molecular and Materials Chemistry	465,000	25	465,000	25
Total	1,860,000	100	1,860,000	100

fuel elements are discharged from the reactor at the end of each fuel cycle. The net result has been a 20% improvement in fuel utilization; the average full power operating time per fuel element increased from 60.6 to 73.2 days. This entailed changing the reactor operating schedule from two 30.3 day cycles to four 18.3 day cycles per full core loading.

Tritium Control Program

Since the HFBR began operating in 1965, the tritium concentration in the primary cooling water system has continued to increase as a result of neutron interaction with deuterium. In order to keep tritium exposure to personnel and environment at a level as low as practical, a program to periodically replace a portion of the primary system D_2O was established. Initially, in September 1974, 27.2 metric tons of D_2O were replaced resulting in a reduction of tritium concentration from 4.27 to 1.41 curies per liter. A second replacement of 15.9 tons in October 1975 brought the tritium concentration down to 1.28 curies per liter. Concurrent with this program, the total tritium exposure to personnel has been reduced from a high of over 8 Rem per year to approximately 3 Rem per year. In like manner, the tritium release to the atmosphere has been reduced from over 700 curies per year to less than 200 curies per year. The D_2O replacement program has been a significant factor in the reduction of chronic tritium impact on both personnel and the environment (Fig. 1 illustrates these improvements).

Quality Assurance Program

In April 1975 the Reactor Division inaugurated a formal quality assurance program. The purpose of the program was to formalize the quality assurance procedures in a systematic manner to provide a consistent level of quality commensurate with the requirements of health and safety, protection of the environment, and reliable and efficient operation. The quality assurance program is described in a new "Quality Assurance Manual" and is carried out under the direction of a Quality Assurance Coordinator.

Operating Difficulties

Lost operating time was held to a minimum during this report period. In February 1975, a scheduled shutdown period was extended 24 hours to allow time to rebuild a 120-cell battery bank which had failed a discharge capacity test. Internal mechanical wear of a primary water pump required eight days of unscheduled downtime in October 1975 to complete inspection, repair, and return to service testing. In February 1976, the reactor operating cycle was terminated four days early due to a fuel element cladding failure. On two other occasions the reactor operation was interrupted for periods of less than one hour.

Two in-core fuel cladding failures were the most significant reactor operating problems encountered during the past two years. In September 1975 an increase in the primary system fission product contamination was observed during the operating cycle. Following the reactor shutdown, investigation revealed a partial delamination of the cladding on one fuel plate of a fuel element. A similar occurrence was experienced in February 1976, at which time the reactor operating cycle was terminated four days early when the fission product contamination in the primary system reached a level high enough to provide confidence that the faulty element could be located. Again a partial delamination of a fuel plate was detected. Both fuel plate failures have been attributed to production difficulties at the fuel fabrication ven-

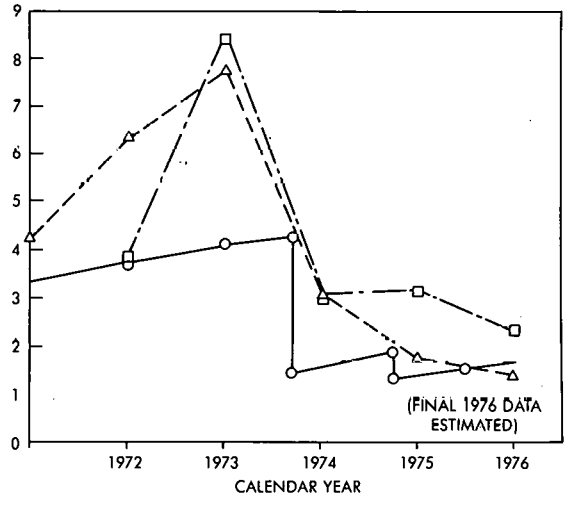


Figure 1. Tritium history at the HFBR, 1972-1976. Solid line (——) shows the tritium concentration in the primary cooling water, in millicuries per milliliter (mCi/ml). Dash line (– – – –) shows the total tritium released to the environment in curies per year (Ci/yr) $\times 10^2$. Dash-dot line (— — —) shows the total tritium exposure to operations, maintenance, and health physics personnel in Rem/yr. Note the marked improvement after replacement of some of the heavy water in the primary system.

dor's plant. Changes in process and quality assurance procedure have been implemented to help ensure that future fuel elements will maintain their integrity. Although both fuel failures resulted in an increase in fission concentration in the primary cooling water system, no detectable fission product activity was released to the environment as a result of these failures.

Future Improvements to Reactor

The Reactor Division has recently received approval to proceed on a project which will increase the normal reactor operating power to 60 megawatts. This 50% increase in thermal power will result in a corresponding increase in neutron flux available to experimental users.

Higher neutron fluxes will have a two-fold advantage in that the time required to perform experiments will be reduced, and new experimental techniques which are only marginally effective at present neutron levels will become practical.

Replacement of the two primary system heat exchangers is the major task in upgrading the reactor to operate at 60 MW. In addition to the new heat exchangers, minor changes will be needed to augment the secondary cooling water and shutdown cooling water systems. Changes to the reactor instrumentation will be primarily range changes on existing systems. It is anticipated that the project will be completed in less than three years, with design, fabrication, and installation of the new heat exchangers being the major critical path items.

BROOKHAVEN MEDICAL RESEARCH REACTOR

The Brookhaven Medical Research Reactor (BMRR) continues to run on a demand basis for short periods each week. As of March 31, 1976 the reactor was run on 246 days and started up 467 times. Total power accumulated to March 31, 1976 was 10,634.73 MWh.

Table II

Irradiations at the Two Reactors for Various Users

	HFBR Fiscal		BMRR Fiscal	
	1975	1976	1975	1976
Brookhaven				
Accelerator Department	3		4	
Department of Applied Sciences	40	38	62	46
Biology Department	2	2	3	1
Chemistry Department	176	130	25	14
Instrumentation		3		0
Medical Department	4	9	340	239
Physics Department	9	11	2	5
Reactor Division	4	4	5	12
HFBR Materials Surveillance Program	20			26
Safety and Environmental Protection Division	2	0	7	17
Outside Organizations	28	25	83	178

A significant new use of the reactor was the conduct of a training program for the Long Island Lighting Company. A number of their prospective operators were trained and practiced in starting and operating the reactor under various conditions.

No significant changes were made in the reactor.

The main utility of the BMRR continues to be its flexibility in providing a wide variety of material irradiations and its large accessible thermal neutron beams. Table II summarizes the irradiations made at both reactors.

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SAFETY AND ENVIRONMENTAL PROTECTION DIVISION

INTRODUCTION

In recent years both the service and research programs of the Health Physics and Safety Division have become more diversified, and now include a number of environmental activities outside the original responsibility of the Division. There has also been increased emphasis on industrial hygiene and safety engineering necessitated by the Laboratory's expanding research program in the non-nuclear areas. In order to recognize the broadened scope of its work, the name of the Division was changed to the Safety and Environmental Protection Division on January 14, 1976.

ENVIRONMENTAL MONITORING

Historically, the principal concern of the environmental monitoring program has been the determination of the levels and concentrations of radioactivity. Recently, an increasing emphasis has been devoted to the assessment of other agents, particularly in the Laboratory's liquid effluents and in the receiving surface waters or ground water. In addition to the on-site effects, the Environmental Monitoring Group is involved in an assessment of the residual levels of environmental radioactivity on the Marshall Islands in the Pacific produced by weapons testing.

Marshall Islands Environmental Studies

Bikini and Enewetak Atolls in the northern Marshall Islands were the sites of high yield atmospheric nuclear weapons tests during the 1940's and 1950's. The original Marshallese inhabitants of these tiny coral islands located some 3300 km southwest of Hawaii were moved to other locations within the Marshalls before the tests began. As a result of negotiations with the United States government they have been granted permission to return to their homeland. Although previous environmental studies at Bikini and Enewetak have demonstrated the presence of residual radioactivity in these islands they have been shown to be safe for habitation; the U.S. ERDA Division of Operational Safety has determined that continuing surveys should be made in the northern Marshalls to provide the necessary reassurances that radiation doses to the repatriated people remain as low as practicable.

Annual field trips to the northern Marshall Islands are usually conducted in the spring by the Safety and Environmental Protection Division in conjunction with the Medical Department survey. The field work entails collection of terrestrial and marine environmental samples which are related to the human food chain, and direct measurement of ambient radiation levels in the islands. The samples are brought to BNL where they are analyzed for radioactivity content. These data are then used to predict radiation doses to the local inhabitants, or to verify the accuracy of earlier dose predictions. Accurate assessments of the small radiation dose contributions from the human food chain are further verified by direct counting of people for internally deposited radioactivity. This is done with an exceedingly sensitive portable whole body counter which accompanies the field trip personnel on an alternate year basis. This study is supplemented by a bioassay program for the analysis of tiny amounts of internal radioactive materials excreted in human waste. These efforts are expected to provide a large measure of assurance for the continued health and safety of the Marshallese people whose homelands were affected by the Pacific Nuclear Testing Program.

DOSIMETRY RESEARCH

In addition to environmental interests the Division has been studying fundamental dosimetry concepts through experimental and analytical investigations for several years. Recently, high energy heavy ions have been studied since they have potential application in the diagnosis and treatment of human tumors.

Nanometer Dosimetry

In order to understand the basic mechanism of energy deposition by heavy ions in tissue-like material, we have used a variable pressure ionization chamber and a mesh-wall ionization chamber to determine energy deposited as a function of radial distance from the ions' path. The experiment was done at the Lawrence Berkeley Laboratory at the 184-inch cyclotron (using 930 MeV ^{4}He ions) and at the Bevelac facility (using 400 MeV/amu ^{20}Ne ions). These measurements were made for distances of a few cm to a few meters in air, simulating distances of a nanometer to a few hundred micrometers in tissue-like material. Measurements were then compared with theoretical model calculations to test the assumptions and input data used in the calculations. These measurements also provide basic information to aid in understanding interactions of these high energy heavy ions with tissue-like material. The interactions in the nanometer region are important since DNA molecules (the basic building blocks of biological systems) have a double strand separation of $\sim$2 nanometers and their alteration is thought to be responsible for many, if not most, biological effects, including production of tumors.

GENERAL AND ADMINISTRATIVE

PERSONNEL

The composition of the scientific staff and the extent to which visiting scientists and students participate in the Laboratory programs are shown in the accompanying tables.

The growth in the regular staff as well as in total employment (Table I) reflects the increased emphasis on energy-related research. The same effect of a broadened and more varied range of research and development is seen in the increased use of a larger number of consultants (Table V).

By contrast, the numbers of academic visitors and students have remained stable or increased only modestly. However, the large absolute number of such visitors gives emphasis to Brookhaven's role as the provider of large scale state-of-the-art facilities to the Nation as a whole. The majority of these visitors and students form groups to conduct experiments at the Alternating Gradient Synchrotron, research so essential to fundamental questions which underlie all energy development. The thousand visitors shown in Table III represent, as shown, 217 different educational and research institutions, a remarkably diverse yet powerful combination of talent.

As would be expected with the Laboratory's close ties to the academic world, a large, vigorous and productive summer visitor program (Table IV) continues to be a conspicuous aspect of Brookhaven. However, while applications for the formal summer student program, which runs for ten weeks and offers a modest stipend, continue to number more than 500 per year, budgetary limits have forced a decrease in the number of students that can be accommodated.

AFFIRMATIVE ACTION

The Laboratory's Affirmative Action momentum is being maintained as demonstrated by the continual increase in its minority and female representation. Minorities presently constitute 11.8% and women 19.5% of the Laboratory's total work force.

Table I

Scientific Staff and Students on May 31

	Regular staff			Salaried visitors		
	1976	1975	1974	1976	1975	1974
By appointment category						
Staff						
Senior Scientist	114	107	98	1	1	1
Scientist	197	186	182	9	5	3
Associate Scientist	127	112	95	8	12	4
Assistant Scientist	86	58	42	3	3	1
Senior Research Associate	–	–	–	7	6	6
Research Associate	–	–	–	71	79	54
Students						
Junior Research Associate	–	–	–	10	7	4
Research Assistant	–	–	–	0	9	0
Total	524	463	417	109	122	73
By academic degree						
Ph.D. or M.D.	411	351	307	94	103	66
Master	45	43	42	4	8	4
Bachelor	62	53	62	11	7	3
No degree	6	6	6	0	1	0

Table II

Employment Statistics

	June 30, 1976	June 30, 1975	June 30, 1974
Scientific staff[a]	620	570	480
Scientific professional staff	359	303	282
Nonscientific staff[b]	1842	1749	1711
Total	2821	2622	2473

	1976		1975		1974	
Turnover data	Number	Annual rate (%)	Number	Annual rate (%)	Number	Annual rate (%)
		Accessions				
Scientific staff[a]	126	20	148	26	85	18
Scientific professional staff	69	19	51	17	26	9
Nonscientific staff[b]	204	11	160	9	156	9
Total	399	14	359	14	267	11
		Separations				
Scientific staff[a]	76	12	58	10	85	18
Scientific professional staff	13	4	30	10	27	10
Nonscientific staff[b]	111	6	122	7	119	7
Total	200	7	210	8	231	9
		Net Accessions				
Scientific staff[a]	50	8	90	16	0	0
Scientific professional staff	56	15	21	7	−1	−1
Nonscientific staff[b]	93	5	38	2	37	2
Total	199	7	149	6	36	2

[a] Includes Research Associates and Visitors.

[b] Figures do not include temporary summer nonstudent employees. Temporary student employees are included in Table I.

Table III

Scientific Guest and Collaborator Appointments (Unsalaried) in Effect at 12/31/75

By department	
Accelerator	5
Applied Mathematics	1
Applied Science	56
Biology	41
Chemistry	104
Instrumentation	5
Medical	168
Physics	647
Reactor	62
Safety & Environmental Protection Division	6
Total	1095[a]

[a] Represents 217 institutions, including 39 outside North America.

Currently, 47.5% of all minorities and 48.9% of all women hold positions in the top three Federal Equal Employment Opportunity Job Categories.

Four participants were offered full time employment after the completion of training as electronic technicians and draftsmen in the NAB-JOBS Program.

A woman firefighter with emergency medical technician certification has joined the Fire Department and there are four women in the ranks of the police officers.

An agreement was established with the Shinnecock Indian Reservation, in support of their CETA Program, to provide training through work experiences. It is anticipated that the program will enhance the employability of the participants at its conclusion. Those selected are being trained as mechanical or health physics technicians.

Two new Affirmative Action Programs have been initiated. The first of these is a Science and Engineering Program which is presently being implemented for minorities and females. This program is receptive to students in the professional, technical and scientific fields. The second program is available to entry level mechanical or electrical technicians and provides methodology which reinforces their basic job skills. There are presently four men and five women enrolled in the Technician Tutorial Program.

ADMINISTRATIVE

On July 1, 1975 Dr. Warren E. Winsche became Associate Director for Energy. In this position he has overall responsibility for the Laboratory's research and development programs on energy systems and energy technologies, including reactor safety support programs for the Nuclear Regulatory Commission.

Dr. Joseph M. Hendrie was appointed Chairman of the Department of Applied Science in July 1975.

On September 1, 1975 Dr. Nicholas P. Samios became Chairman of the Physics Department.

Mr. Harvey Thomas was appointed Assistant to the Director for Affirmative Action in October 1975.

In November 1975 Dr. Robert Marr, who had been serving as Acting Chairman, was appointed Chairman of the Department of Applied Mathematics.

The Laboratory's concern for energy conservation was affirmed in November 1975 with the appointment of Mr. Lewis Jacobson of Plant Engineering as the Laboratory Energy Conservation Coordinator.

The National Center for Analysis of Energy Systems was formed at the Laboratory in January 1976 and Dr. Kenneth C. Hoffman was appointed Head of the Center and Associate Chairman for Energy Programs in the Department of Applied Science.

The National Center for Analysis of Energy Systems (NCAES)is designed to assist the Energy Research and Development Administration in the formulation and execution of a balanced and diverse energy research and development program that is responsive to the nation's needs. The programs carried out at the Center are comprehensive and multidisciplinary, allowing the detailed study of the complex interrelationships between technological, economic, social, and environmental factors that influence energy policy.

In April 1976 Henry C. Grahn, Budget Officer of the Laboratory, was appointed Assistant Director for Financial Planning. In addition to his continuing responsibility in the Budget Office, he is in charge of the Administrative Data Processing Group, previously a part of the Department of Applied Mathematics. This reflected a shift in responsibility for the operation of the ADP administrative computer and associated administrative systems development activity from the Applied Mathematics Department.

In May 1976 Dr. James R. Sanford was appointed Associate Director for the ISABELLE project.

Table IV

Summer Program

	1975					1976				
	Staff	Students[a]	Salaried	Unsalaried	Institutions	Staff	Students[a]	Salaried	Unsalaried	Institutions
By department										
Accelerator	5	15	18	2	13	3	14	17	–	12
Applied Math	5	3	4	4	7	6	4	6	4	9
Applied Science	29	34	48	15	39	19	43	44	18	38
Biology	1	9	9	1	10	5	10	11	4	14
Chemistry	–	1	1	–	1	16	10	12	14	23
Directors Office	–	1	1	–	1	–	1	1	–	1
Instrumentation	–	1	1	–	1	2	1	3	–	3
Medical	1	13	13	1	13	–	18	15	3	15
Physics	87	21	40	68	69	80	18	48	58	65
Safety & Environmental Protection Division	–	16	14	2	9	–	10	9	1	6
Total	145	118	156	107		139	129	166	102	

[a]Includes 65 participants in Summer Student Program for 1975; 55 for 1976.

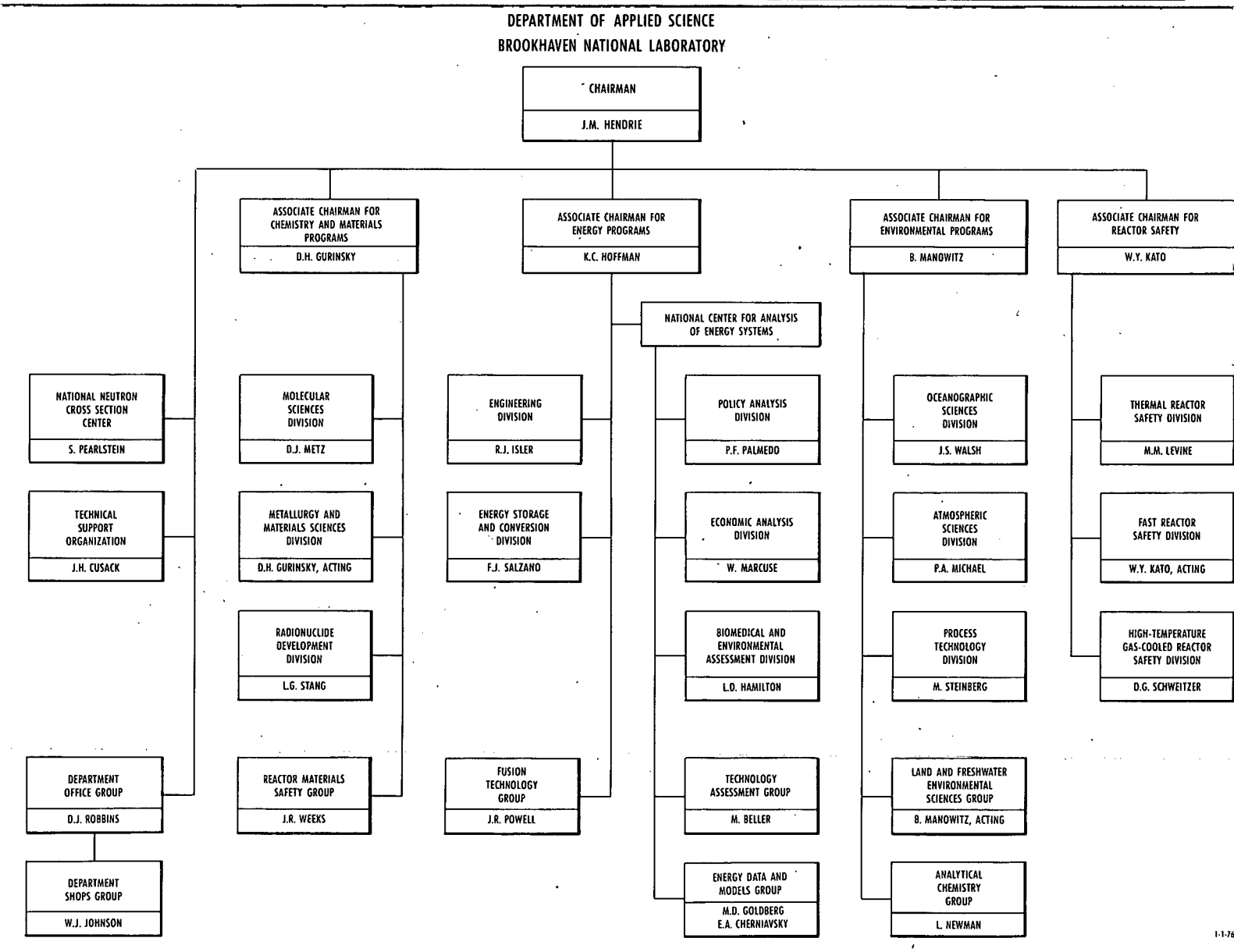

Table V

Consultants' Services

	Fiscal year	
	1975	1976
Total contracts in effect	140	232
Number of consultants used	105	194
Number of man-days of service	1,466.63	2,205.68

In June 1976 Mr. Alfred P. Lewis was appointed Manager of the Purchasing Division.

In December 1975 the Applied Mathematics Department was restructured into the following organizational units: Computer Science Research, Mathematics Research, Computer Services Division and Technical Support Division.

The Accelerator Department formed an ISABELLE division in May 1975. This division will coordinate all aspects of the research and development work for this future project.

The recent expansion of the Department of Applied Science and the redirection of its major efforts to energy-related research and development has necessitated considerable reorganization of DAS, so an organization chart as of January 1, 1976 is included here.

In recent years both the service and the research programs of the Health Physics and Safety Division have become more diversified, and now include a number of environmental activities outside the original responsibility of the Division. In order to recognize the broadened scope of its work, the name of the Division was changed, effective February 1, 1976, to the Safety and Environmental Protection Division.

TECHNOLOGY UTILIZATION

The Technology Utilization Office (TUO) was organized in April 1974 to seek out technology generated by the scientific programs and make it readily available to nonfederal government agencies and to the private sector. It is also responsible for the patent review functions and the more technical aspects of public information activities. Reflecting the broadened concerns of the Energy Research and Development Administration, the TUO has been asked to provide staff assistance to the energy programs in the commercialization of their activities.

The TUO is the northeastern representative of the technology transfer network established by the ERDA. To aid its liaison activities in the heavily industrialized eleven northeastern states, the TUO has established a group of seven volunteer engineers and scientists who act as local field officers, referring industrial, scientific, and engineering problems to the Laboratory.

Brookhaven National Laboratory has recently joined the Federal Laboratory Consortium, a technology transfer organization funded by the National Science Foundation, designating the TUO as the liaison agent. This consortium provides local governments with a broad spectrum of technical advice from its member laboratories which are drawn from many branches of the federal government.

At the Laboratory the TUO has participated in the sponsorship of a number of technical conferences, on federal technology transfer, on solar energy, on business opportunities with ERDA, and on energy conservation. The latter topic was presented to commerce and industry, to the building industry, and to the public at an Energy Fair in May 1976, organized jointly with the Public Relations Office, and drawing an attendance in excess of 30,000. Energy conservative houses on display at the fair have attracted commercial attention. Modified versions are expected to be on the market within a year.

SERVICE ORGANIZATIONS

The Photography and Graphic Arts Division has established a Micrographic Group by installing as a nucleus a high-resolution Computer Output Microfilm System (COM). Initial applications of the COM have concentrated on the transfer of computer output from paper to microfiche. Future applications will involve complex graphics in two and three dimensions as well as color; revision and rejuvenation of engineering drawings; printed circuit boards; numerical control applications; and the publishing of scientific and administrative reports, catalogs and directories.

The Word Processing Center of the Graphic Arts Group has effectively doubled its capabilities with additional personnel and more sophisticated equipment. The Center now provides service on both the day and evening shifts.

The Quick Copy Service Center has improved its service, and reduced its turn-around time and

costs by installing two Xerox 9200 copiers. These machines are the newest, fastest and most sophisticated copier-duplicators presently available in this area.

On-site housing facilities managed by the Staff Services Division were increased by permanently locating sixteen mobile homes in the housing area. The mobile homes were acquired from surplus property excessed by Housing and Urban Development (HUD).

AUI support of the university user community, previously provided by full time lease of aircraft and employment of pilots, is now being furnished by an aircraft charter company. The new arrangement reduced the costs and increased the flexibility of aircraft employment for transporting university personnel to and from the Laboratory in support of research.

The Supply & Materiel Division has been conducting the annual physical inventory of Stores, utilizing the Haskins & Sells Auditape procedure. This method requires a physical count of a small number of line items which account for a significant portion of the dollar value. It also provides the ability to project the sample results over the entire inventory population with a very high reliability factor. This procedure has resulted in a savings of 1½ man-years, while reducing the Fiscal and Administrative Data Processing support effort.

During 1975 Supply & Materiel instituted a weekly processing by Administrative Data Processing of the inventory system which includes stores issues, requisition cards, and receiving information. This greatly reduced processing time and has not adversely affected inventory levels or customer demands on stores.

In order to meet the Laboratory's growing need for bulk gaseous helium supply, Supply & Materiel has embarked on a program of establishing a BNL-owned fleet of reconditioned tube trailers. The Laboratory presently has four such units in service which will result in a cost savings of $60,000 in rental charges over the next five years.

ENERGY CONSERVATION

By early Fiscal 1975 BNL had gone beyond the "quick fixes" and was actively engaged in an energy management program. The Central Steam Facility was a prime area for energy control. Combustion controls on the three older boilers were updated in order to improve their performance and to increase their efficiencies. Additional soot blowers were installed in the main boiler to remove accumulated soot and improve heat exchange efficiency. The oil storage tanks were painted a flat black so that solar energy can aid in pre-heating the fuel. The steam distribution system was extended to the Bubble Chamber Work Area to allow the elimination of an independently fired heating unit.

The Accelerator Department initiated its Save-A-Watt Program. When the AGS must be temporarily shut down its operation is switched by computer into the save-a-watt mode, going from a power level of about 23 megawatts down to a standby level of about 5 megawatts.

Through the alertness of personnel in the Purchasing and Plant Engineering Divisions, three million gallons of virgin oil were recovered for use in our Central Steam Plant. This oil, stored in the hulls of inactive ships and deemed excess by the Navy, was transported to Brookhaven from the Philadelphia Navy Yard at a cost of approximately 13 cents per gallon, for a savings of $600,000.

Cooling tower improvements, started in Fiscal 1974 have been completed. Operational efficiencies were improved and energy consumption reduced on twenty major heating, ventilating, and air conditioning (HVAC) systems through the use of chemical treatment systems and mechanical modifications. Conversion of thirteen centrifugal refrigeration machine controls to solid-state electronic types was initiated in order to improve reliability and utilize energy more efficiently.

Electrical loads have been redistributed so that lightly loaded transformers totaling 7,500 kVA could be de-energized to eliminate transformer core losses.

To aid in the development of our energy program the services of consulting engineering firms were utilized. Fuel Systems Design Corporation is investigating and analyzing the operation of the Central Steam Plant. Dubin, Mindell & Bloome Associates were engaged to do an in-depth building analysis of the Chemistry Building and to do a pre-feasibility site study for a five-year energy conservation program. Holzmacher, McLendon and Murrell are working on a detailed study of our water supply.

Plant Engineering in conjunction with the Department of Applied Science and the Town of Brookhaven, New York, has been investigating

various concepts of land utilization in the treatment of raw sewage and septic tank pumpings.

Energy savings resulting from these measures are difficult to assess; however, they are believed to be significant. Comparison of the electric power consumption and fuel consumption in Fiscal 1975 with Fiscal 1973 indicates a 7% reduction in electric power use and a 20% reduction in fuel. These reductions were achieved at a time when the Laboratory has been increasing its staff and expanding its operations; approximately 47,000 square feet of building space were opened and a new CDC Cyber 70/76 computer went on line in Fiscal 1975.

In January 1976 the Laboratory published its Energy Conservation Plan which detailed conservation measures implemented to date, together with near term conservation proposals and those in the planning stages for the long term.

BROOKHAVEN NATIONAL LABORATORY

ORGANIZATION CHART

July 1, 1976