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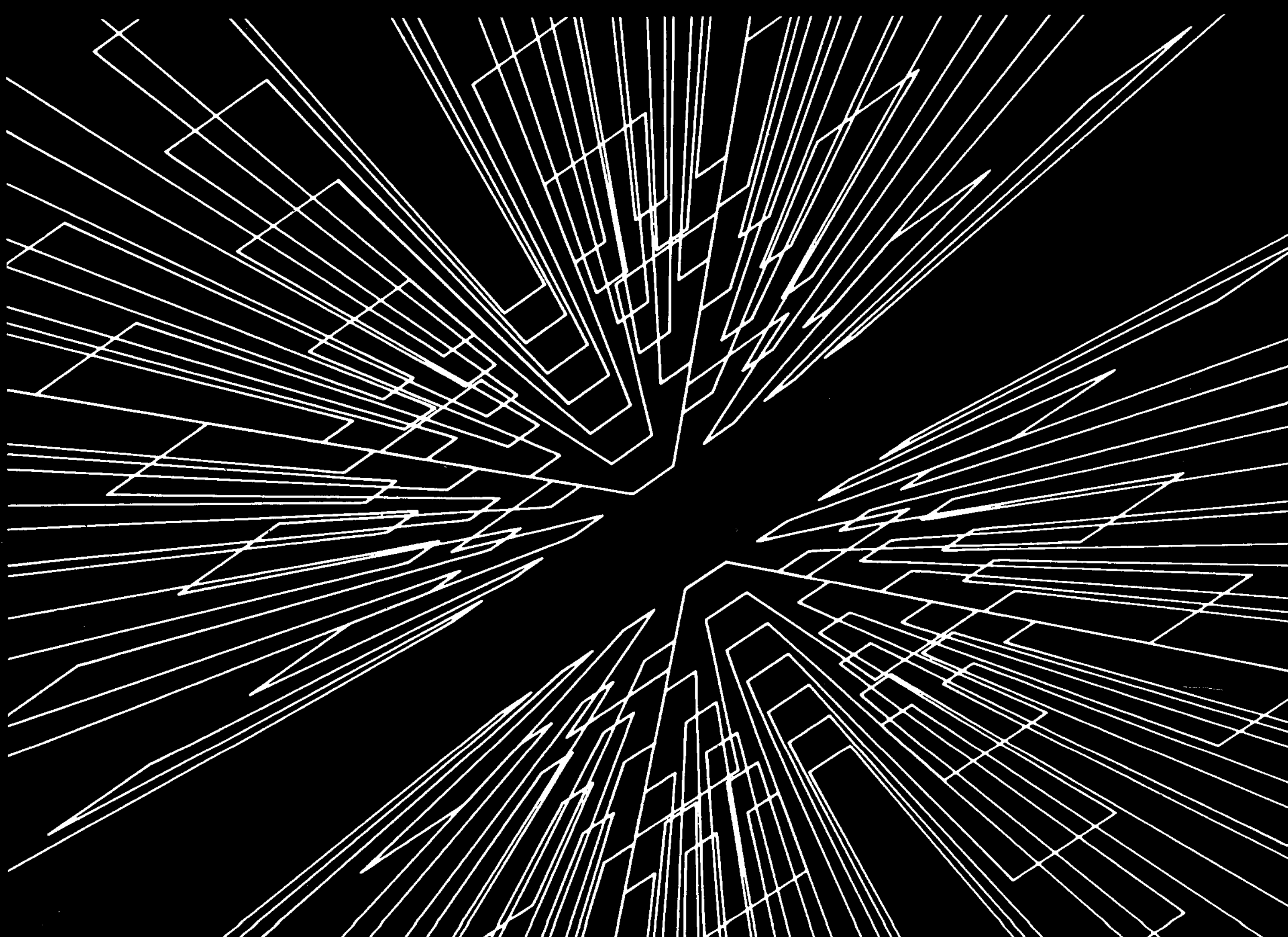
BES

Office of Basic Energy Sciences

1984 Summary Report



The Office of Basic Energy Sciences is one of several program offices in the Department of Energy's Office of Energy Research and plays an important role in the support of basic research in the United States today. The program is strongly oriented toward developing the information and understanding required for the long-term technological capability of the nation. This program is organized along the disciplinary lines of research science to effectively interact with the scientific community. The program summaries that describe the BES subprograms are also organized by scientific disciplines, but the basic research conducted under the auspices of several of our divisions often has a common underlying energy theme. A survey of research activities relevant to improving our insight into problems and solutions of long-term nuclear waste isolation, for instance, will span several disciplines. Conversely, a given project can impact more than one energy technology; this illustrates the merits of basic research.

This report is a summary document on the Basic Energy Sciences program, its overall scope, the kinds of activities carried out, and the unique facilities that have become a key part of our ability to conduct forefront research.

Donald K. Stevens

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Deputy Associate Director for Basic Energy Services

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Office of Basic Energy Sciences 1984 Summary Report

A summary of the organization, mission, and activities of the Office of Basic Energy Sciences

U.S. Department of Energy
Office of Energy Research
Office of Basic Energy Sciences
Washington, D.C. 20545

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Introduction

Over the years, a tradition of leadership in science and technology has evolved in the United States that has led other nations to emulate us. Today it is our basic research activity, carried out mainly in universities and government laboratories that underpins continuing U. S. leadership in science, provides for the training of future scientists, and contributes to our social and economic well-being. Our national goals—better health and quality of life for all our people, economic growth, energy self-sufficiency, national security, reduction in the arms race, etc.—involve technological advances that depend on basic research. Knowledge and discoveries resulting from research provide the foundation for new ideas and concepts to stimulate technology development and economic growth.

This past year, for example, saw the selection of a new material developed at DOE's Oak Ridge National Laboratory as one of the 100 best technology achievements in the United States for 1983. The material, nickel aluminide with minor alloying additions, is one of a class of lightweight structural alloys that are a direct outgrowth of continuing basic research to understand the relationship of the properties of materials to their structure and composition at the atomic level.

Nickel aluminide already is attracting industrial interest. Through alloying, it can be made ductile and easy to fabricate; it is made of lightweight and inexpensive materials; and it is six times stronger than stainless steels at high temperatures. This newly developed alloy overcomes a major problem that has prevented the wide use of intermetallic compounds like the aluminides for structural applications. The nickel aluminides are strong and resistant to corrosion and high temperatures but, until this development, were too brittle to be suited to structural applications. At room temperature, this new material's strength is comparable to commercial superalloys, and it actually becomes stronger at higher temperatures. This example illustrates how basic research contributes to continued technological innovation; the prospects for early commercialization of this new material for structural applications are promising.

Basic research is a painstaking activity requiring long-term commitments of resources and people with little promise of early success or return on investments. Thus the support of long-range basic research has emerged as the particular responsibility of the federal government as the only institution with the motivation, capability, and continuity to carry it through.

This report briefly describes the program of the Department of Energy's Office of Basic Energy Sciences, which is responsible for basic research in the scientific disciplines from which contributions to our long-term energy goals are likely to come. The Basic Energy Sciences subprograms and facilities are discussed, along with an abbreviated budget summary and an outline of plans for the future. Reports referenced are normally available from the National Technical Information Service, U. S. Department of Commerce, Springfield, VA 22161.

Overview

The Office of Basic Energy Sciences (BES), which reports to the Department of Energy's (DOE) Director of Energy Research, is the office responsible for long-range basic energy-related research and is charged with providing the fundamental scientific foundation on which the nation's future energy options depend. The organization of BES, which is primarily discipline oriented, is shown in Fig. 1. Research is sponsored in selected areas of the traditional scientific disciplines—the physical and biological sciences, geosciences, and engineering. The subprograms of BES support approximately 1200 individual research projects, each one selected on the basis of its scientific merit, its possible relevance to meeting the BES long-range research goals, and its contribution toward a balanced, responsive research program.

The knowledge that results from BES-sponsored research becomes a part of the body of information on which the applied technologies rest. Although research to broaden the technology base needed for identified energy options is extremely important, even more important is the need for basic research, unfettered by preconceived notions of what technologies will be important several decades from now, so that new, not yet identified options may emerge. Because of its diversified interests, with centralized management and common goals, BES can respond quickly and efficiently to DOE and national missions. The scientists and engineers of BES include professionals with years of experience in fostering and conducting creative basic research and managing major complex research facilities.

Any discussion of BES must consider that:

- BES is oriented toward DOE's energy mission.
- BES is a major participant in the physical and engineering sciences efforts of the nation.
- BES is a principal source of support of university research and of the national laboratories.
- BES is involved in the construction and operation of large and complex scientific facilities.

The energy supply and conservation missions of DOE are so vital to the nation's future that a comprehensive program of basic energy- related research is essential. It is the responsibility of BES to plan and administer DOE's program of basic research in the physical, biological, and engineering sciences exclusive of high-energy and nuclear physics and the medical and environmental sciences. The multipurpose national laboratories are national assets and play an essential role in U. S. science and technology, maintaining expert scientific and engineering staffs, building and operating complex scientific facilities, and undertaking large interdisciplinary projects. A large fraction of the BES budget goes to the national laboratories to support research, much of it dependent on complex facilities and services at the laboratories.

Basic Energy Sciences has a heavy involvement in scientific facilities (e.g., the National Synchrotron Light Source at Brookhaven National Laboratory, the Combustion Research Facility at Sandia-Livermore, the High Flux Isotope Reactor at Oak Ridge National Laboratory, and high-voltage and atomic resolution microscopes). Many areas of modern science require large and costly facilities; without them the necessary research could not be done. The large, expensive, unique facilities in the BES program are made available to the entire basic research scientific community to the extent that funds permit the additional shifts of operation.

Most of the scientists involved in BES research programs are at universities and national laboratories. University research receives support in several ways, e.g., "financial plan" funding, in which rather large sums of money are allocated to institutions to support identified projects but the institution is delegated authority to manage the overall program of research; special research contracts (and, in the future, grants) to support the research of individual scientists with graduate assistants, which is the largest form of university support; and support of two national laboratories that are co-located with universities—Lawrence Berkeley Laboratory at the University of California and Ames Laboratory at Iowa State University. In addition, free access by qualified scientists is provided to user facilities at national laboratories. More than one-third of BES funding supports university-based research. An important fringe benefit resulting from supporting research in universities is the research training of graduate students who continue in R&D after completion of their studies.

In addition to universities and national laboratories, BES maintains ties with industry. Representatives of appropriate industries serve on counseling committees for several of the BES subprograms; experts from industry participate in the review of research proposals and use the specialized facilities

Figure 1 Office of Basic Energy Sciences organizational chart.

Office of the Associate Director
R. H. Kropschot
Deputy Associate Director
D. K. Stevens

Division of Materials Sciences
L. C. Ianniello

Division of Chemical Sciences
E. S. Pierce

Division of Engineering and Geosciences
J. S. Coleman

Division of Carbon Dioxide Research
F. Koomanoff

Division of Advanced Energy Projects
R. Gajewski

Division of Biological Energy Research
R. Rabson

sponsored by BES; industrial scientists participate in program advisory committees at the national laboratories; and industry representatives are invited to attend the BES conferences and workshops. Through these and other mechanisms available to and used by the scientific community, the results of the BES program are available to industry and to the academic community.

The Basic Energy Sciences program also is a participant in the Congressionally mandated Small Business Innovation Research program, which was initiated in Fiscal Year 1983. A number of BES projects are being supported at highly specialized, research-oriented small business firms. The level of this effort was 0.6% of the BES research budget in Fiscal Year 1984—i.e., about $1,500,000—and will increase to 1% in Fiscal Year 1985 and 1.25% in Fiscal Year 1986.

The Office of Basic Energy Sciences evolved from the Division of Physical Research of the Atomic Energy Commission. The Office expanded its activities with the formation of the Energy Research and Development Administration in 1975 and again with the establishment of DOE in 1977. Each transition broadened the scope of its responsibilities for research in energy technologies, e.g., from nuclear to fossil, solar, and conservation. For over 35 years, BES has responded to the needs for basic research in areas of national priority.

Research in BES is conducted under seven subprograms: Materials Sciences; Chemical Sciences; Nuclear Sciences; Engineering and Geosciences; Advanced Energy Projects; Biological Energy Research; and Carbon Dioxide Research. At present, programmatic priorities call for emphasis in the areas of Biological Energy Research, Advanced Energy Projects, and Engineering and Geosciences. Other areas currently being emphasized include:

- High-temperature materials— corrosion, ceramics, and coatings
- Synthesis of novel materials
- Chemistry and physics of combustion processes
- Surface modification
- High-voltage and atomic resolution microscopy
- Condensed matter theory
- Amorphous materials
- Chemical structure and behavior of coal
- Structural ceramics
- Synchrotron radiation research
- Catalytic mechanisms and surface phenomena
- Neutron scattering research
- Photochemistry
- Nuclear data for fusion reactions
- Nondestructive evaluation

Each of the subprograms is described briefly in the following chapter. The major objective of BES—to provide the basic scientific knowledge and insight necessary to develop new and improved energy options—is pursued through several concurrent approaches, some already identified. They are to:

- Provide critical knowledge and data and develop trained scientific talent through support of highly competent researchers in DOE mission areas
- Provide for and support the operation of unique, specialized research facilities
- Maintain liaison with other DOE programs, federal agencies, and the scientific, academic, and industrial communities
- Seek the scientific and industrial communities' identification of needs and opportunities for research in areas likely to be relevant to future energy options
- Expand research into new areas identified as having potential importance to energy
- Promote application of the results of basic research

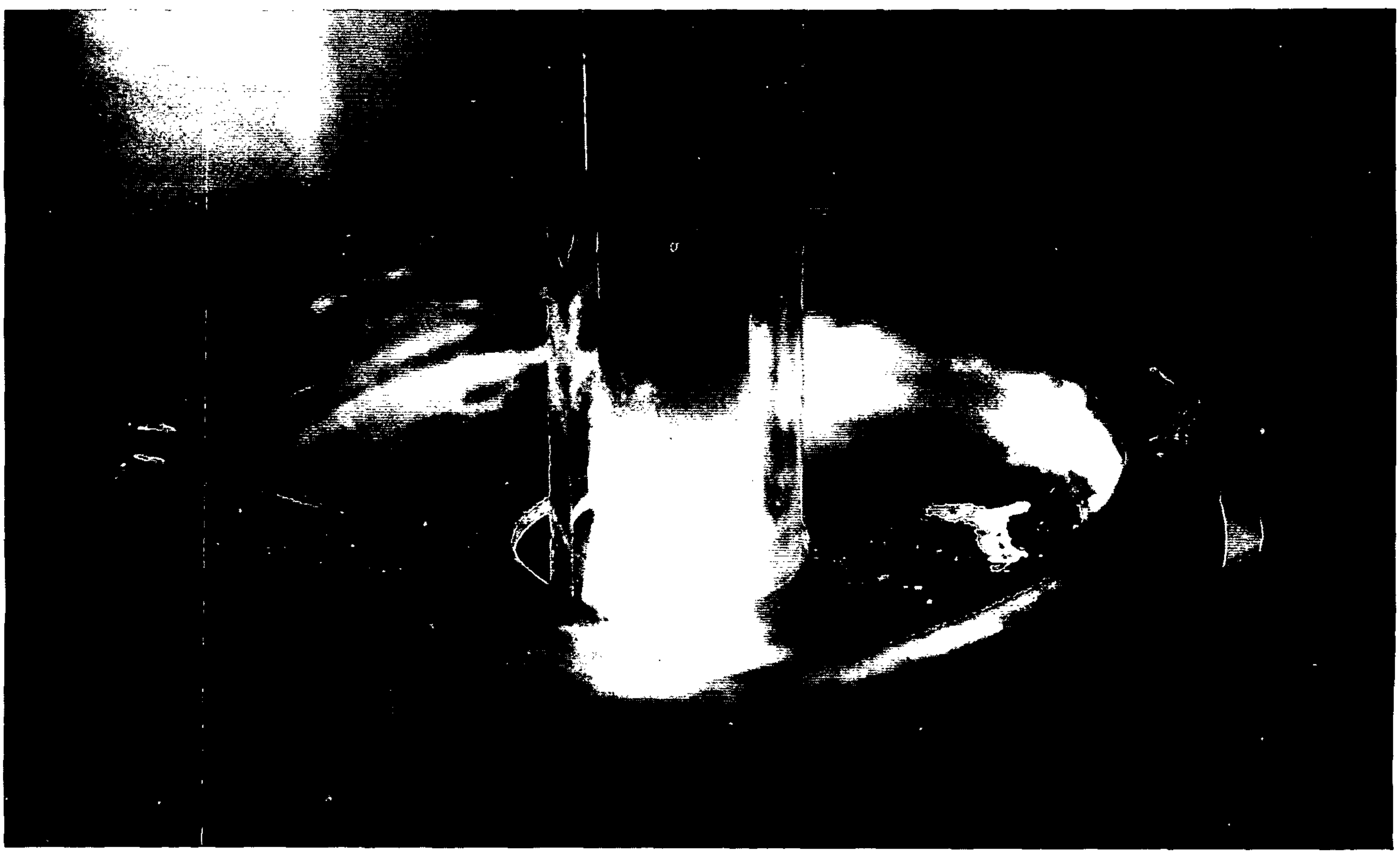
Interagency information exchanges, committee interactions, and workshops provide useful liaison between BES and other research groups. For example, DOE offices and laboratories and such federal agencies as the National Science Foundation, the Nuclear Regulatory Commission, and the U. S. Geological Survey have working groups and committees that routinely exchange information and coordinate program activities in such common research areas as nuclear data, chemistry, geophysics, hydrogen, materials, and combustion research. Coordinating committees discuss individual proposals and compare work being done by the various agencies to avoid overlap and duplication of effort. Outreach workshops and working groups bring together investigators in related areas to share information and discuss problem areas in their work. Finally, and most importantly, study results always are published in the open literature to make them available to the scientific community worldwide.

The Discovery of Glassy Metals and Their Future Potential

Questions often are raised about the role basic research plays in the mission of the Department of Energy or about its priority in relation to the near-term needs in the technologies being developed by the applied research of the Department. The development of a new class of materials called glassy, or amorphous, metals illustrates the long-term contribution of basic research. The genesis of glassy metals can be traced directly to basic research sponsored by the Materials Sciences subprogram 25 years ago. Glassy metals differ in structure and properties from metals as we usually think of them. Normally, metals have a crystalline structure, with atoms arranged in periodic arrays called lattices. In contrast, atoms in glassy metals do not form periodic arrays—their distribution is random. Originally devised a quarter of a century ago, the technique of producing amorphous metals requires cooling the molten metal about one hundred thousand times faster than had previously been possible. Extremely rapid cooling is the only way to prevent mobile atoms in the molten metal from rearranging themselves into crystal lattices. The amorphous metal produced with rapid cooling has been limited to very thin films because heat must be removed so quickly. Recently, more advanced techniques of materials science have been brought to bear on the problem of producing thicker samples, e.g., controlled diffusion of chemical elements into and out of the crystals, which causes them to become amorphous.

The current work grew out of methods of dealing with an early problem involving the empirical rules used by physical metallurgists to describe the formation of complete solid solutions in binary alloys. An exception to the rules was a copper–silver system that, on cooling, yielded two different solutions, both of very limited solubility, instead of the anticipated complete binary solution. It was thought that the molten mixture would be cooled rapidly enough to by-pass the reaction point and produce the expected solution. This took place in 1959.

The new, successful rapid cooling technique was applied to other binary systems, and new crystalline phases were produced. Within a few months, a non-crystalline gold–silicon metallic solution was found in an amorphous state similar to glass but having the electrical conductivity characteristic of a metal. By 1970, about 100 papers on metastable alloys and their properties had been published. It was concluded at that time that the inherent requirements of the heat-transfer process would always limit the thickness of



these "liquid-quenched metastable alloys" and any useful applications of them. Today, some 14 years later, new techniques of ion implantation and controlled diffusion have removed that limitation. Continuing research focuses on better understanding of this new approach, how to control it, and the nature of the resulting materials. Thus, advances in materials sciences have made feasible a current research goal of producing massive samples of amorphous metals rather than thin films.

The first uses for metallic glasses will be in magnetic applications. A unique feature of the amorphous structure is that it can be magnetized and demagnetized with lower losses of energy than can a crystalline structure. Energy losses that occur when the magnetic field is reversed are a problem in power transformers, where crystalline steels are now used throughout the United States. The losses in magnetic energy in these transformers are estimated to cost over six hundred million dollars per year; it has been estimated that most of this annual cost could be saved by substituting amorphous metals for the steels. There also are other magnetic applications—e.g., the recording and playback "heads" in tape recorders and the starting circuits in fluorescent lights. Thus, through technology transfer, the original research already is leading to significant commercial use of glassy metals in communication and lighting.

Subprograms

Materials Sciences

The goal of the Materials Sciences subprogram is to increase understanding of the phenomena and properties important to materials behavior; this understanding is essential to the development of future energy technologies. It is well-known that materials problems and limitations often restrict the performance of current energy systems and the development of future systems. Some needs to which Materials Sciences research ultimately contributes include:

- Developing new or substitute materials
- Tailoring materials to satisfy defined requirements
- Predicting materials problems and service life
- Improving the ability to successfully attack unforeseen materials problems in advanced energy systems
- Improving the theoretical and experimental capability to analyze the fundamental structure of materials

With support at an operating level of $125 million in FY 1984, the BES Materials Sciences subprogram provides about one-third of the total federal funding for basic materials research. Materials Sciences places emphasis on selected generic areas of fundamental importance and on areas where problems are known to exist or are anticipated. Some research is directed at a single energy technology (e.g., photovoltaic materials for solar energy conversion); some research has applicability to many technologies simultaneously (e.g., embrittlement of structural materials in the presence of hydrogen); and still other research has more fundamental implications underpinning all materials research (e.g., mechanisms of atomic transport in solids). The research is conducted in a variety of institutions—DOE laboratories, universities, and, to a lesser extent, industrial installations—and uses the talents of metallurgists, ceramists, solid-state physicists, and materials chemists.

In addition to maintaining an appropriate mix of long-term scientific, multitechnology, and single-energy-technology-related research, a balance must be retained among forefront, large, facility-related research and small individual projects. The Materials Sciences subprogram uses some major facilities in the pursuit of its research goals, including the National Synchrotron Light Source and the High Flux Beam Reactor (HFBR), both at Brookhaven National Laboratory; the Surface Modification and Characterization Collaborative Research Center and High Flux Isotope Reactor at Oak Ridge National Laboratory; the Intense Pulsed Neutron Source at Argonne National Laboratory; the high-voltage electron microscopes at Oak Ridge, Argonne, and Lawrence Berkeley Laboratories; and the Stanford Synchrotron Radiation Laboratory (SSRL) at Stanford University. The operation of these facilities required about 21% of the FY 1984 operating budget of the Materials Sciences subprogram, not including the research associated with them. Most of these facilities are unique, as is the research carried out at these sites. The facilities are also available to qualified users outside the DOE laboratory complex.

The agency's materials program is coordinated primarily through the DOE Energy Materials Coordinating Committee. The Materials Sciences subprogram is the basic materials program in DOE, which underpins the energy materials technologies. It represents about 20% of the total DOE materials research and development effort. The fact that there is four times as much effort in applied materials development is testimony to the crucial role materials play in the development of energy systems. Within the federal government, the subprogram is coordinated in part through the interagency Committee on Materials (COMAT). The workshops and reports of the subprogram's Council on Materials Science (a nongovernmental body with representatives from academia, industry, and agency laboratories) help to focus attention on critical issues. In 1983, panel meetings on coatings and surface modifications and on conducting organic materials were held. In 1984, the two meetings were on computer simulation and materials synthesis. The agency's applied materials research workers interact and exchange information through a number of mechanisms, including a formalized Research Assistant Task Force.

Current emphases and trends are toward greater use of the major facilities.

More detailed information on this subprogram can be obtained from Louis C. Ianniello, Director, Division of Materials Sciences, Office of Basic Energy Sciences, Department of Energy, Washington, DC 20545. A detailed summary of current projects is published annually. The most recent (September 1984) is entitled "Materials Sciences Program, Fiscal Year 1984" (DOE/ER-0143/2).

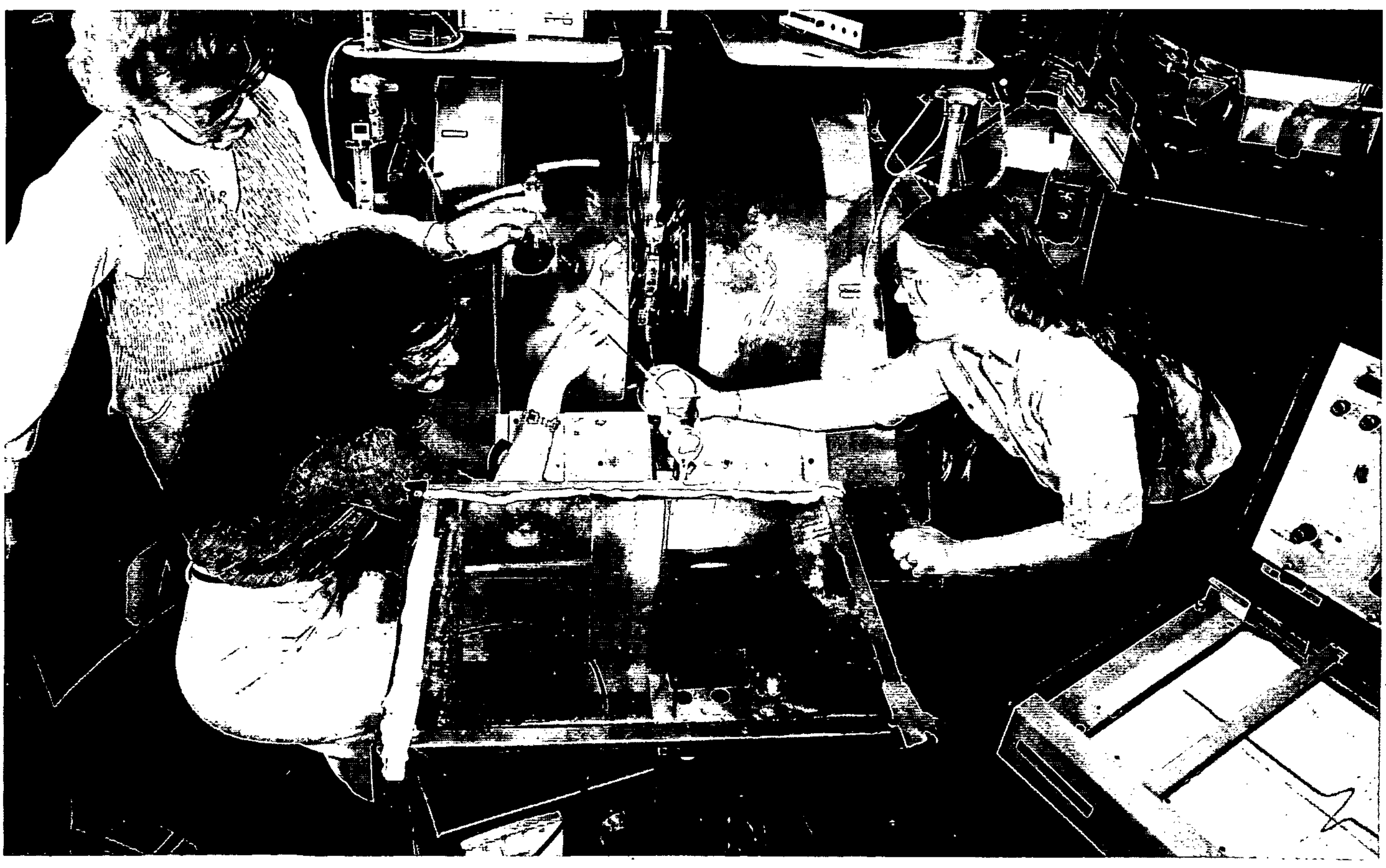
Chemical Sciences

The research activities supported by the Chemical Sciences subprogram range from energy-related phenomena involving liquids, gases, and plasmas to the chemical properties of solids, such as coal, chlorophyll, and catalysts, and the phenomena and behavior of submicroscopic particles, such as molecules, atoms, ions, and electrons.

The objective of Chemical Sciences is to expand the knowledge base in the chemical and related sciences in areas most likely to lead to new ideas and improved processes for developing and using domestic energy resources. At a budget level of $76 million, this subprogram is a major source of federal support for basic chemical research in the United States.

Phenomena and processes likely to be important to energy technologists are emphasized in the formulation of the program. Research in some areas, such as the chemical effects of catalysts, may lead to discoveries that can be quickly exploited by industrial process designers; whereas in others, such as water-splitting photochemistry to produce hydrogen, research may not be used for a number of years. Still other research areas, such as studies of radiation emitted by ions moving very fast through crystal foils, produce data for use in developing new energy technologies.

The Chemical Sciences subprogram includes research in the fields of photochemistry, coal chemistry, catalysis, atomic physics of highly charged ions, chemistry basic to nuclear waste separation, biomass conversion of liquid fuels by enzyme catalysis and other methods, energy-efficient separation of valuable metals from low-grade resources, efficient and clean combustion of various fuels, and detection and measurement of harmful by-products of energy processes. Equally important is the fundamental research into chemical and physical phenomena which has no immediately identifiable related technology. A typical example of such efforts is the study of laser-induced excited states of molecules. Disciplinary areas covered by Chemical Sciences work include physical, organic, and inorganic chemistry; chemical physics; radiation chemistry; thermodynamics; thermophysics; and analytical chemistry.



Much of the Chemical Sciences research centers on the special facilities at DOE's national laboratories—the Combustion Research Facility, National Synchrotron Light Source, electron linear accelerators, ion accelerators, superconducting nuclear magnetic resonance spectrometers, very advanced molecular beam machines, differential speed-of-light fiber optics, etc. In addition to their unique equipment, DOE laboratories provide enhanced opportunities for interactions between basic researchers and research and development teams in related energy technology areas. University laboratories carry out a large part of the remaining work, and a small part takes place in industrial laboratories. Laboratory scientists supported by Chemical Sciences also interact with industrial research workers, such as those in the automotive and petroleum industries.

Coordination with energy technology programs is emphasized. Laboratory-based interactions between the basic researchers in Chemical Sciences and the applied technology teams are assisted by headquarters-based coordination. Various conferences and committees—e.g., the Hydrogen Coordinating Committee, Solar Photochemistry Research Conferences, and Coal Chemistry and Catalysis Research Meetings—identify research needs and opportunities, compare results, and coordinate activities within DOE and with the rest of the scientific community. In addition, Chemical Sciences staff members serve as advisors for energy technology activities and visit and review activities at the DOE national laboratories.

Additional detailed information on the Chemical Sciences subprogram can be obtained from Elliot S. Pierce, Director, Division of Chemical Sciences, Office of Basic Energy Sciences, Department of Energy, Washington, DC 20545. A detailed summary of current projects is published annually. The most recent (September, 1984) is entitled *Summaries of FY 1984 Research in the Chemical Sciences* (DOE/ER-0144/2).

Nuclear Sciences

The objectives of the BES Nuclear Sciences subprogram are to:

- Measure, compile, and evaluate nuclear data for fission and fusion energy technologies
- Improve knowledge of the chemical and physical properties of the actinide elements
- Assure the availability for research of isotopically enriched samples of the elements
- Operate the Stanford Synchrotron Radiation Laboratory
- Conduct heavy ion fusion accelerator research

Nuclear Data

The fission and fusion energy technologies require nuclear data for optimization of reactor design, analysis of operations and safety of reactor systems, and management of spent fuel materials. The nuclear data activity provides a long-range base of data in support of these technologies. Nuclear data needs are documented in great detail and are regularly updated—for *fission* technology, through the work of the Cross Section Evaluation Working Group of the National Nuclear Data Center (NNDC), and for *fusion* technology, by means of a working group of the U. S. Nuclear Data Committee and DOE's Office of Fusion Energy.

The compilation and evaluation effort is concerned with establishing a data base for neutron-induced nuclear reactions and also with maintaining the Evaluated Nuclear Structure Data File (ENSDF), which encompasses all the information produced worldwide on the level structure and decay properties of nuclei.

The nuclear data compilation and evaluation effort is centered around the NNDC at Brookhaven National Laboratory, which coordinates a network of scientists performing compilation and evaluation for ENSDF and also coordinates U. S. work with the International Atomic Energy Agency. Data compilation and evaluation activities devoted to ENSDF and the publication of the Nuclear Data Sheets are monitored by an advisory panel of the National Academy of Sciences. Annually, NNDC processes about 700 requests for nuclear data from scientists and engineers in the energy technologies, biomedical scientists, and basic researchers.

The nuclear data measurement effort is centered around the Oak Ridge Electron Linear Accelerator for measurement of neutron cross sections over a wide range of energies. Several small university groups and the National Bureau of Standards collaborate in these activities.

Heavy Element Research

The nuclear energy and technology programs of DOE need specific information and data on the behavior of actinides in fuel processing streams, in nuclear waste hosts materials, and in the environment. Heavy element chemistry research helps meet their needs, as well as contributing to an understanding of the fundamental chemical and physical properties and behavior of matter. These broadly based studies of the actinide elements include behavior in aqueous and nonaqueous solutions, photochemistry, chemical reactivity, spectroscopy, and chemical physics.

Research groups at national laboratories and universities are supported to pursue heavy element (actinide) and radiochemical investigations. The study of actinide chemistry is largely limited to the national laboratories since high levels of radioactivity are involved, but some tracer work is done at universities. These laboratory facilities provide opportunities for visiting scientists from university and foreign labs to pursue collaborative research with the U. S. investigators. The heaviest elements are produced by irradiating curium-loaded targets in the High Flux Isotope Reactor (HFIR) and chemically processing the targets in the Transuranium Processing Plant (TRU) to extract and purify the actinide samples. These samples are allocated to investigators engaged in DOE research programs.

Isotopes Separations

Nuclear Sciences also supports the electromagnetic separation of stable isotopes for a Research Materials Collection of samples that are loaned out for nondestructive research in DOE energy technology programs. In addition to its research and information-gathering activities, Nuclear Sciences is responsible for distributing the stable isotopes and the rare, heavy radioactive isotopes it produces for use in research, medicine, and industry. These efforts constitute the western world's only source of isotopic research samples in significant quantities, and these materials are sold or loaned to institutions throughout the world.

Stanford Synchrotron Radiation Laboratory

Basic Energy Sciences is responsible for operating the Stanford Synchrotron Radiation Laboratory (SSRL). The SSRL was expanded under the auspices of the National Science Foundation in partial response to a National Academy of Sciences report that pointed out the potential for research in the newly identified area of synchrotron radiation. The SSRL, which shares the Stanford Positron Electron Asymmetric Ring with the high-energy physics program, is an important research facility; at present it is heavily oversubscribed by the solid-state, chemical, and biomedical research communities for its high-intensity photons in the ultraviolet and X-ray regions of energy. This is one of two major BES facilities where research of this kind is made possible.

Heavy Ion Fusion Accelerator Research

Research on heavy ion accelerators for potential application to inertial fusion is a recent addition to the energy mission of Basic Energy Sciences. The Heavy Ion Fusion Accelerator Research (HIFAR) program, a spinoff from high-energy accelerator physics, is managed by the Office of High Energy and Nuclear Physics. The program goal over the next several years is to establish a data base in accelerator physics and technology that can allow the promise of the accelerator approach to be accurately assessed.

The experimental program concentrates on developing a multiple-beam-induction linear accelerator (linac) to provide the necessary high-current beam of heavy ions. This type of accelerator has intrinsic characteristics that make it attractive as an inertial fusion driver:

- It is conceptually simple, involving a minimum number of beam manipulations.
- Adequate pulse repetition rates (30 to 100 pps) and good efficiency (15 to 25%) are expected.
- Considerable experience exists with kilo-ampere electron beams in induction linacs.
- The most serious technical issues of the method can be demonstrated in a small- to medium-sized accelerator.

These characteristics and, in general, the promise of this method of fusion energy have been verified in a number of national reviews, studies, and technical workshops.

The most important recent accomplishment in the HIFAR program was the development of conceptual designs for an accelerator to demonstrate a substantial fraction of the physics and engineering principles of a full-scale inertial fusion driver. Preliminary designs indicate, for example, that a heavy ion accelerator at one-tenth to one-twentieth of the cost of a fusion plant accelerator will demonstrate key design parameters at one-third full scale. Tests at this scale would provide the Department of Energy with an ample data base on which to base decisions on the future of this fusion method.

The accelerator to accomplish these goals has been named the High Temperature Experiment (HTE) because all the various tests of accelerator performance and a test of the heavy ion beam target interactions can be combined in one measurement; e.g., the temperature of the dense plasma produced by focusing the accelerated beam into a small spot on a plane slab target. Concurrently, recent experimental programs have shown that the highly space-charge-dominated ion beams required for such accelerators are feasible. This result has broad applications not only to fusion drivers but also to all high-current particle accelerators and thus is a spinoff of the HIFAR program.

Most of the current research activities in the HIFAR program are conducted at the Lawrence Berkeley Laboratory and the Los Alamos National Laboratory. The program is coordinated with the Office of Inertial Fusion within the Department's Defense Programs.

Additional information on the nuclear data activities can be obtained from Enloe Ritter, Director, Division of Nuclear Physics, Office of High Energy and Nuclear Physics; on the HIFAR program from Terry F. Godlove, Program Manager, Office of High Energy and Nuclear Physics; and on the other aspects of the Nuclear Sciences subprogram from Elliot S. Pierce, Director, Division of Chemical Sciences, Office of Basic Energy Sciences, all at the Department of Energy, Washington, DC 20545.

Engineering and Geosciences

The Engineering and Geosciences subprogram supports research in mechanical, structural, and electrical engineering; geology; geochemistry; and geophysics. Priorities are established through extensive interaction between experts in technological communities in the fields of interest, building on the well-documented studies of the Energy Research Advisory Board, the agency's comprehensive review of its own technology activities, and studies by the National Academy of Sciences and others.

The objective of engineering research is to advance the engineering science needed for energy production facilities and for increased energy efficiency. At present, three research areas are receiving high priority:

- Mechanical sciences, including tribology (the basic nature of friction-reduction phenomena), heat transfer, and solid mechanics (continuum mechanics and engineering aspects of crack propagation)
- Systems sciences, including process control, instrumentation, and scale-up of process plants
- Engineering analysis, including nonlinear dynamics, thermophysical properties of fluids, and engineering combustion

One of the current projects in tribology provides a useful example of the type of research under way. An attempt is being made to establish a sound experimental basis for a new theory of viscoelastic composites to predict the internal rolling friction of a tire. Automobile efficiency is reduced as a result of the rolling friction of tires—typically 10% or more of the engine horsepower is lost here. Eventually it should be possible to predict the best tire design to maximize fuel mileage without reducing tire life, traction, or safety—the three traditional tire performance criteria.

Engineering research also includes work on instrumentation for measuring basic engineering quantities—temperature, pressure, flow rates, and phase—under extreme conditions of temperature or pressure and efforts to model complex systems to develop predictive capabilities for the scale-up of pilot process plants.

The objective of the Geosciences program is to develop a quantitative, predictive understanding of the energy-related aspects of geological, geophysical, and geochemical processes both in the earth and at the solar–terrestrial interface.

The Geosciences program is emphasizing (1) long-range research on the geological isolation of nuclear waste, (2) studies in organic geochemistry relating to fossil fuel recovery and the disposition of energy-related chemical waste, and (3) studies of the magma-hydrothermal part of the interagency Continental Scientific Drilling Program.

The effort in nuclear waste isolation addresses unresolved problems with second- and third-generation repositories (e.g., quantitative assessment of local changes of stress, with subsequent development of new fracture systems, which provide pathways for the migration of nuclear wastes; interactions among waste container, rock, and fluids in the rock; and concentrations, diffusion rates, and element migration of nuclear wastes from a disposal site into its surroundings).

The organic geochemical processes of migration, physical changes, and maturation of fossil energy resources are also being studied. Such knowledge is essential if fossil fuels are to be effectively exploited and is required for dealing with the problems of organic wastes.

The Magma Energy Research project, having demonstrated the scientific feasibility of extracting energy from magma bodies, has been phased out, but the DOE portion of the national Continental Scientific Drilling Program (CSDP) will continue to be focused on magmahydrothermal systems. A cooperative interagency program, CSDP seeks to develop an understanding of the North American continent. The DOE part will aid in predicting deposits of energy and mineral resources, establishing a scientific base of information relevant to nuclear waste isolation, and assessing hazards associated with the siting of major energy-related facilities. So far, programs of shallow and intermediate depth drilling have been initiated, and a drill-hole data base for holes drilled for the federal government has been established.

Other research involves rock mechanics, geodynamics, advanced geophysical techniques, resource definition and use, and solar–terrestrial relations.

More information on this subprogram can be obtained from James S. Coleman, Director, Division of Engineering and Geosciences, Office of Basic Energy Sciences, Department of Energy, Washington, DC 20545.

There are two reports available which supply more detailed information on this subprogram:

Summaries of FY 1984 Engineering Research, DOE/ER-0158/2, December 1984.

Summaries of Physical Research in the Geosciences, DOE/ER-0145/2, September 1984.

Advanced Energy Projects

The objective of the Advanced Energy Projects (AEP) subprogram is to explore the feasibility of novel energy-related concepts evolving from basic research which are at an early stage of scientific definition and, therefore, would not be of interest to technology programs. To qualify for AEP support, such concepts, even though they involve a high degree of risk, must have the potential for an eventual high payoff. Advanced Energy Projects also sponsors exploratory research on concepts that do not fit easily into the existing DOE program structure. An area of major attention is the transfer of successful projects to technology programs; a number of such transfers have already been made.

A relatively new BES subprogram, Advanced Energy Projects supports individual projects for a limited time only, with the goal of supporting about 20 new projects each year. It differs from other subprograms in that it does not fund ongoing, evolutionary research.

After a period of concentrated effort, typically about 3 years, the concept is expected to have proved itself, in which case the basic research phase is completed and the project can be transferred to a technology program. If a successful conclusion to the research is not foreseeable, the project is dropped. Projects are selected from unsolicited proposals received from researchers at universities, industrial laboratories (especially small R&D companies), and national laboratories. Currently, 36 projects are being supported; this allows a turnover rate of about 12 projects per year.

Advanced Energy Projects is an interdisciplinary program whose projects cover a broad technological spectrum, e.g., new approaches to controlled fusion, completely new methods of solar energy concentration and collection, ultrasonic coal grinding, new heat engines, the development of X-ray lasers, and new methods of accelerating charged particles.

A recent accomplishment of this subprogram is a finding that fusion reactions, when "catalyzed" by elementary particles called muons, occur at a much higher rate than had been predicted when this approach to controlled fusion was first suggested in the 1950s. This realization, following from AEP-supported experiments proposed by scientists from the Idaho National Engineering Laboratory, could lead to a new look at this intriguing option of effecting fusion reactions at essentially room temperatures.

Additional information about the current activities of this subprogram is available from Ryszard Gajewski, Director, Division of Advanced Energy Projects, Office of Basic Energy Sciences, ER-16, Department of Energy, Washington, DC 20545. An annual report, *FY 1984 Research Summaries* (DOE/ER-0150/2, October 1984), also provides more detailed information on this subprogram.

Biological Energy Research

The principal objective of Biological Energy Research is to provide basic information and conceptual understanding in microbiological and botanical sciences for DOE's efforts in renewable resource production of fuels and chemicals, microbiological transformation of organic materials for conservation, and biological systems for resource recovery. The research is aimed at gaining an understanding of the underlying mechanisms of green plant productivity, converting biomass and other organic materials into fuel and chemicals by novel and improved methods of fermentation, and developing biosystems capable of saving energy.

The Biological Energy Research subprogram focuses on understanding the limits of productivity in green plants, how plants adapt to suboptimal conditions of growth, such as those encountered in marginal lands and waters, and the mechanisms of microbial conversion of various biomass forms. In particular, the biochemical pathways and their genetic and biochemical regulation relating to degradation of abundant materials such as cellulose, hemicelluloses, and lignins and the conversion of these materials to fuels or chemicals are studied.

Microorganisms that grow in the absence of oxygen and are able to carry out fermentation with high efficiency are of special interest, as are thermophilic microorganisms, which have optimal growth and conversion rates at high temperatures. An integral part of the subprogram is the development of genetic information that may ultimately be used to produce new or improved microorganisms and plants to facilitate the production of fuels or petroleum-conserving chemicals or to yield biotechnologies capable of conserving energy.

This research into the physiology, biochemistry, and genetics of microorganisms and plants is carried out primarily at university laboratories.

Further information on this subprogram can be obtained from Robert Rabson, Director, Division of Biological Energy Research, Office of Basic Energy Sciences, Department of Energy, Washington, DC 20545. Also available is the *Annual Report and Summaries of FY 1984 Activities* (DOE/ER-0147/2, October 1984), which provides detailed descriptions of ongoing activities.

Carbon Dioxide Research

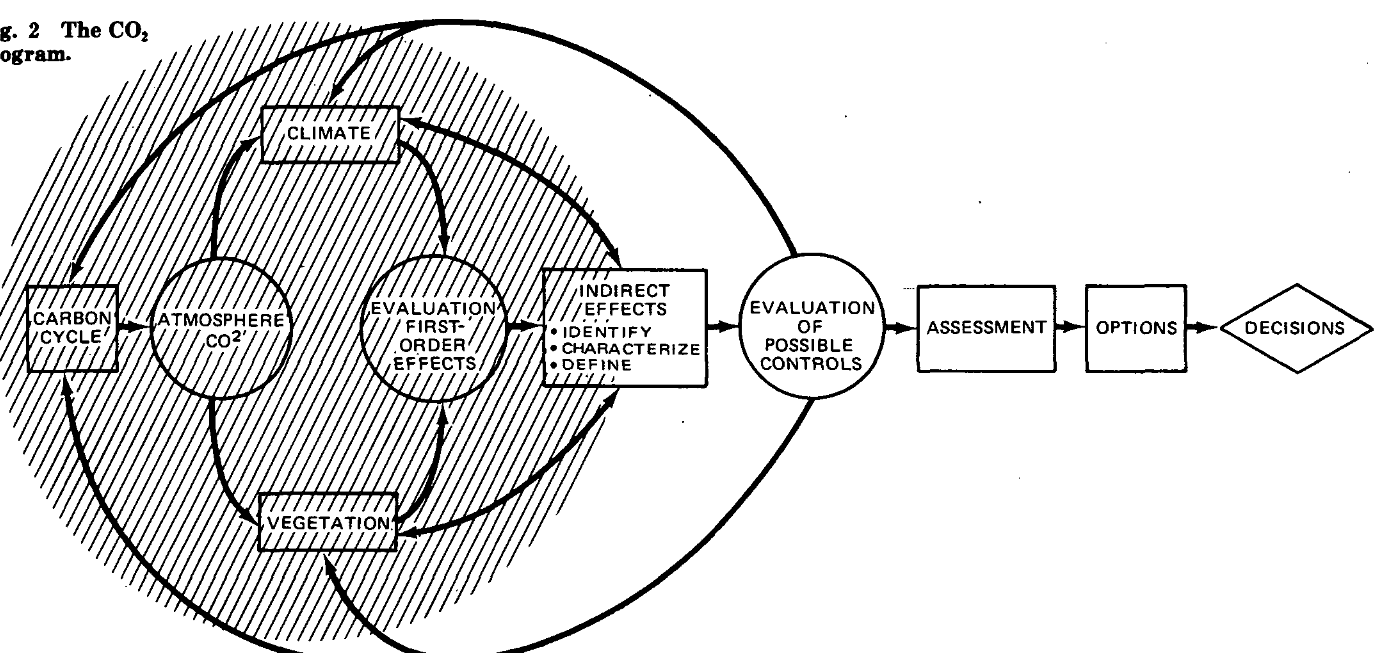
Detailed worldwide measurements indicate that the amount of carbon dioxide (CO_2) in the earth's atmosphere is gradually increasing. Scientific analysis suggests that such an increase could have substantial effects on climate and on agriculture and other human endeavors.

The goal of the Department of Energy's Carbon Dioxide Research Program is the identification of possible policy options for governmental action in response to these changes. The achievement of this goal requires a significant increase in our scientific knowledge of the atmosphere, the biosphere, the oceans, and the cryosphere—their interactions and the effects that increasing atmospheric CO_2 and other trace gases will have on them. To identify and specify choices that are valid, we must gather accurate scientific data and develop the necessary computer models through which we can:

- Project future atmospheric CO_2 concentrations
- Estimate CO_2-induced global and regional climate changes
- Estimate crop and ecosystem response to higher CO_2 concentrations
- Evaluate human health and welfare effects attributable to CO_2-induced climate and vegetation changes

With these data, it should be possible to consider innovative concepts and strategies by which people can modify and/or adapt to these potential changes. Assessments of risks and cost/benefit analyses can be conducted so that potential options for decision making can be based upon a truly comprehensive

Fig. 2 The CO_2 program.



understanding of CO_2-induced changes.

Carbon Dioxide Research aims to establish knowns and unknowns, reduce and specify uncertainties, increase data collection, and improve measurements and models directed at answering specific questions about the sources and sinks of CO_2, climate, and other possible effects.

Much of the current research is focused on defining and measuring fluxes of CO_2 among major sources and sinks of the carbon cycle. Research efforts also include estimates of global and regional changes in temperature and precipitation aimed at identifying which climate changes result directly from the effects of CO_2 (as differentiated from the many other factors that could have been involved). General circulation models are being used to determine how atmospheric CO_2-induced climate change may relate to the nonatmospheric components of the climate system, such as oceans, land, and the cryosphere. Preliminary results of studies with nonatmospheric-ocean models suggest that effects may be delayed a decade or more by the thermal inertia of the oceans. The photosynthesis, physiology, and water use of plants and trees are also being studied to provide a basis for predicting the responses of vegetation to rising atmospheric CO_2.

In 1977, recognizing the paucity of scientific data and the uncertainties surrounding our understanding of possible global climate change as a function of increasing atmospheric CO_2, DOE and several other federal agencies began a concerted effort to define the CO_2 issue. The DOE initiated a new research program, the first step being to convene a series of workshops and conferences. These workshops led to commissioned papers, which in turn became the basis for long-term research plans. A focused research program has, thus, been designed to develop the scientific knowledge base to aid in analyzing possible energy policy options related to potential CO_2 effects. The efforts of DOE and the other agencies are now being coordinated by the National Climate Program Office, established by the National Climate Program Act (P.L. 95-367) and administered by the National Oceanic and Atmospheric Administration. The DOE is the lead agency for investigation of CO_2. Other agencies involved in the program include the National Aeronautics and Space Administration, the U. S. Geological Survey, the Department of State, the Environmental Protection Agency, and the National Bureau of Standards. The major efforts of the Carbon Dioxide Research program are currently focused on the cross-hatched areas of the figure on page 14.

Additional information about this subprogram is available from Frederick A. Koomanoff, Director, Division of Carbon Dioxide Research, ER-12, Office of Basic Energy Sciences, Department of Energy, Washington, DC 20545.

Major BES Facilities

Basic research in most areas pertinent to the DOE mission requires highly complex equipment and facilities. As mentioned earlier, the construction and operation of such facilities is costly, but many research projects rely on their availability. Basic Energy Sciences currently operates a number of facilities that are unique in the United States and, in some cases, in the world. The major BES facilities are described and their functions discussed briefly in the following subsections.

High Flux Beam Reactor

Brookhaven National Laboratory, Upton, New York

The High Flux Beam Reactor (HFBR) produces high-intensity neutron beams for research in a wide variety of fields. Neutrons are used as probes by nuclear and solid-state physicists, chemists, and biologists. Neutron scattering techniques continue to yield information on the fundamental properties and behavior of materials and chemical and biological substances which cannot be obtained by any other means. The HFBR is one of two high-flux research reactors supported by DOE, both of which are world-class research reactors for neutron research.

Current research using the HFBR includes studies of:

- The structure and dynamics of magnetic materials by elastic and inelastic neutron scattering
- The dynamics of materials as they change phase by quasi-elastic neutron scattering
- Neutron irradiation effects on the physical properties of materials
- The molecular structure and dynamics of organometallic substances
- Small-angle neutron scattering of biological substances
- The lattice structure and dynamics in condensed matter systems
- Amorphous materials—short-range order and excitations
- The neutron spectroscopy of low-lying excited states in solids

The HFBR, which cost $12.5 million to build, went critical in 1965 and attained full power in 1966. Originally 40 MW, its power was increased to 60 MW in 1982. The reactor has a maximum thermal neutron flux of 1.1×10^{15} neutrons/cm^2-sec available for research. Several of the nine experimental beam ports are used by more than one scattering instrument; three are used for nuclear physics research, and the rest for neutron diffraction or scattering research. The reactor can also be used to irradiate samples through any one of seven different vertical access tubes. The in-core total flux is 2.4×10^{15} neutrons/cm^2-sec. The building that houses the reactor and ancillary equipment has floor space for experimental apparatus. A cold moderator facility, recently installed, establishes HFBR as the largest source of very low energy neutrons in the United States.

High Flux Isotope Reactor

Oak Ridge National Laboratory, Oak Ridge, Tennessee

The High Flux Isotope Reactor (HFIR) has a high thermal neutron flux designed for production of transplutonium elements. This facility is critical to the Transplutonium Production Program of DOE. In addition to producing transplutonium elements, HFIR has four ports to permit the extraction of neutron beams from the reactor core for experimental purposes. The high flux and experimental capabilities make HFIR a unique research reactor, important not only for isotope production but also for neutron scattering, nuclear chemistry, and radiation damage research.

Although the use of HFIR has changed direction over the years, with increased emphasis on neutron irradiation and beam research and radioisotope production for sales, transplutonium isotope production continues to be the major effort. With the shutdown of the General Electric Test Reactor, which was a commercial supplier of a variety of radioisotopes, HFIR provides substantial quantities of radioisotopes to the industrial community. These sales, at full cost recovery, have resulted in revenues to HFIR of about $600,000 to $800,000 annually.

The HFIR cost about $15 million to build and attained its operating power of 100 MW in 1966, with a thermal flux in the target area of 2 to 5×10^{15} neutrons/cm^2-sec. It has a unique, one-piece core, which is its fuel element; this core is about the size of a 30-gal drum and is replaced after about 3 weeks of operation. In addition to isotope production activities and in-core irradiations, there are twelve research stations at four experimental ports. Associated with the HFIR is the National Center for Small Angle Scattering Research, sponsored as a joint project of DOE and the National Science Foundation.

In FY 1983 total HFIR operating costs were about $6.7 million, of which about $1.0 million was defrayed by non-BES user research programs and radioisotope sales. BES-supported research activities at HFIR in FY 1983 were at about $5 million. Other research at HFIR is supported by the Fusion and Fission Energy Programs, the Nuclear Regulatory Commission, and the National Science Foundation.

National Synchrotron Light Source

Brookhaven National Laboratory, Upton, New York

The National Synchrotron Light Source (NSLS) is a unique user-oriented facility for advanced multidisciplinary research with synchrotron radiation. At NSLS a wide range of research techniques are used by biologists, chemists, solid-state physicists, metallurgists, and engineers for basic and applied studies. Among the techniques are extended X-ray absorption fine structure (EXAFS), scattering, diffraction, topography, fluorescence, interferometry, gas phase spectroscopy, photoemission, lithography, microscopy, dichroism, and infrared vibrational spectroscopy.

The highly intense radiation emitted by electrons travelling in circular paths at very high energies is referred to as synchrotron light. Synchrotron light radiation from the NSLS is continuous in spectrum, stable, pulsed, and high in intensity, with the spectral peak related to the electron energy and radius of the circular orbit. Some applications of the interaction of synchrotron radiation with matter are:

- Studies of the state and behavior of gases
- Studies of the surface of solids
- Studies of metal atoms in biological systems
- Analysis of the atomic structure of microscopic samples
- Microscopy
- Research related to the miniaturization of computer chips

The NSLS, which began operating in 1981, includes two electron storage rings—an X-ray ring about 170 m in circumference, which provides 28 photon ports, each able to handle one or more experiments, and a vacuum ultraviolet (VUV) ring 44 m in circumference, with 16 photon ports. A common injector meets the high-current requirement (1.0 A) for both rings. The VUV ring has been used routinely for research since early 1984. It operates at 750 MeV and has achieved peak currents over 400 ma with average 100 ma lifetimes of more than 2 hours. The x-ray ring is in the commissioning stage. It has operated at 2.0 GeV with 70 ma, about 15% of the design current. Some initial experiments are being staged. The users of the NSLS facility include individual university researchers, national laboratory teams, and industrial researchers from such Fortune 500 corporations as IBM, Exxon, Bell Laboratories, DuPont, General Electric, and Mobil. The authorized construction cost for NSLS ($24 million) provided for the building, storage rings, and a limited amount of experimental equipment for four of the beam ports. Substantial additional instrumentation and equipment has been installed, with private industry committing more than $8 million.

Stanford Synchrotron Radiation Laboratory

The Stanford Synchrotron Radiation Laboratory (SSRL) is one of several national facilities for the utilization of synchrotron radiation for basic and applied research in chemistry, physics, biology, and materials science. The available synchrotron radiation is produced by the 4-GeV storage ring SPEAR operated by the Stanford Linear Accelerator Center (SLAC). The SSRL is a user-oriented facility that welcomes inquiries and proposals for experiments from qualified scientists.

The extraordinary properties of synchrotron radiation as a research tool have led to many very important scientific results including:

- Development of the Extended X-ray Absorption Fine Structure (EXAFS) technique as a powerful structural tool
- Many advances in surface physics based on the photo-emission technique, using high intensity tunable VUV radiation from 10 to 1000 eV
- Dynamic studies of conformational changes in biological systems, using time dependent x-ray diffraction and fluorescence lifetime techniques
- Development of anomalous diffraction as a broadly applicable tool of crystallography
- Results in other areas such as topography, lithography, and microscopy

CAPTION: The photograph is an aerial view of the 4-GeV storage ring spear and SSRL laboratories at SLAC. The SSRL is housed in two buildings on the spear ring. The building in the forefront houses the offices and three beam lines. The building on the opposite side of the ring houses another three beam lines and support facilities. The large double-peaked building inside the ring contains the storage ring control room and power supplies. Entering the ring tangentially from the right are the electron and positron injection lines. The cleared space in the forefront of the picture is the site of the new light assembly building being constructed under the SEP Program.

SSRL has many experimental stations in operation. These provide white radiation and monochromatic radiation over a broad spectral region from the visible through the ultra-violet and deep into the x-ray region to 40 KeV and beyond.

Synchrotron radiation is available in either dedicated or parasitic mode. Half of the time, the SPEAR ring is operated in high-current single-beam mode as a dedicated synchrotron radiation source. During the other half of the time, radiation is available during colliding beam runs for high-energy physics research. In colliding beam runs, radiation occurs in 200 to 400 picosecond pulses at a rate of 1.28 MHz.

During dedicated runs, the SPEAR energy that best satisfies user needs is selected; this is generally 2.6 to 3.7 GeV, with most operation near 3.0 GeV. The stored current is typically 75 to 100 mA. Most colliding beam operation is at or near 2.0 GeV, with stored electron currents of about 10 mA.

Synchrotron radiation, the electromagnetic energy produced by relativistic electrons in magnetic fields, has many unusual properties that make it a most effective experimental tool. The SPEAR spectrum extends from the infrared through the visible, UV, VUV, and deep into the x-ray region. As a continuum source, synchrotron radiation is unrivaled. For example, in the x-ray region, SPEAR provides five orders of magnitude more continuum radiation than the most powerful conventional x-ray generators in many experimental situations.

SSRL has six beam lines, most with multiple experimental stations.

Intense Pulsed Neutron Source

Argonne National Laboratory, Argonne, Illinois

The Intense Pulsed Neutron Source (IPNS) is a dedicated user-oriented facility for advanced multidisciplinary research with pulsed neutrons, serving the physics, materials, chemical, and life sciences research communities.

Unlike reactor sources, this machine provides high fluxes of neutrons in bursts that are synchronous with the 30 Hz frequency of the proton accelerator. High-energy protons from a proton synchrotron impinging on a heavy metal target produce bursts of spallation neutrons. The resulting pulsed beams of neutrons, exploited using time of flight techniques, have the following characteristics:

- High peak intensity thermal neutrons
- High peak intensity epithermal neutrons
- Pulsed delivery for investigating time-dependent phenomena, such as following shock waves, heat pulses, or laser flashes

In materials research, pulsed neutrons can be used to study:

- Static and dynamic properties of liquids and amorphous solids
- Defects, voids, and aggregates in materials
- Structure and dynamics of polymers and biological material
- Magnetic, crystallographic, and electronic changes
- Phonon structure and magnetic excitations in solids
- Surface phenomena and superconductivity
- Radiation damage studies at cryogenic temperatures

The IPNS, which began operation in FY 1981, has the following operating characteristics:

Proton current	8 μA
Protons/pulse	2×10^{12}
Proton energy	500 MeV
Repetition rate	30 Hz
Peak thermal flux	3×10^{14} neutrons/ cm^2-sec
Peak epithermal flux (1 eV)	10^{15} neutrons/ cm^2-sec
Time-average fast flux (0.1 MeV)	2×10^{12} neutrons/ cm^2-sec

The neutron scattering assembly has seven spectrometer stations, and the radiation effects assembly includes two cryostat stations for investigations at 4°K. Six additional facilities are available for special experiments with, for example, solid He^3, polarized neutrons, and ultracold neutrons, and for high-temperature irradiations. During the initial experimental period in 1982, 29 of the 38 experiments performed were by outside users.

The authorized construction cost for IPNS ($6.4 million) provided for beam transfer from the proton synchrotron and construction of the spallation target area. In addition, $2.4 million was provided to upgrade the experimental capability with a variety of spectrometers, detectors, and computer interfaces.

Combustion Research Facility

Sandia National Laboratory, Livermore, California

The Combustion Research Facility (CRF), which cost $10.3 million, provides a range of instrumentation not available in other laboratories and, thus, provides a unique capability to outside users for combustion research. It receives considerable use by non-DOE groups. The focus of the laboratory is on laser diagnostics of combustion systems, but a variety of burner systems and special facilities are available, including those for research on coal combustion and internal combustion engines. The staff at CRF provides users with technical support covering such diverse fields as chemistry, fluid dynamics, computer modeling, and pure and applied spectroscopy. The CRF research staff also has the necessary scientific strengths to serve the DOE combustion program's research objectives—maximizing the efficiency of processes while minimizing the production of undesirable pollutants. Examples of research that is carried on at CRF include:

- Detection and measurement in flames of short-lived reactive intermediates in key combustion reactions
- Modeling and improvement of the use of ammonia to reduce NO_x emission from combustion processes
- Laser velocimetry to study turbulence effects in an internal combustion engine
- In situ laser diagnostics of the interactions of materials surfaces with flames

The CRF, a building with fourteen individual research laboratories, four special laser laboratories, and a variety of support laboratories, was dedicated in early March 1981. On demand, laser output can be beamed to any one of the individual research laboratories for use in a large variety of experiments.

High-Voltage and Atomic Resolution Electron Microscope Facilities

High-Voltage Electron Microscopes (HVEM) are invaluable for energy-related research important to, e.g., fission and fusion (radiation damage), automotive (high-strength steel and high-temperature ceramics for automotive turbines), fossil (corrosion), and solar (photovoltaics) technologies. The microscopes are also important for general research, and each institution having one has developed or is developing a sizeable outside user group of academic and industrial scientists.

The HVEM is useful for transmission electron microscopy of heavy metals, studies that must use "thick" samples to avoid surface effects, and studies of brittle materials, such as ceramics, which are difficult to prepare in thin form. Also, high-voltage machines are necessary for materials studies incorporating special environments and for in situ radiation damage studies. It is possible to "see" damage as it is being produced. The only other federal agency supporting MeV microscopes is the National Institutes of Health, which has several machines for medical and biological research.

Basic Energy Sciences supports three facilities with HVEM's and the atomic resolution microscope (ARM), which came on-line in 1983.

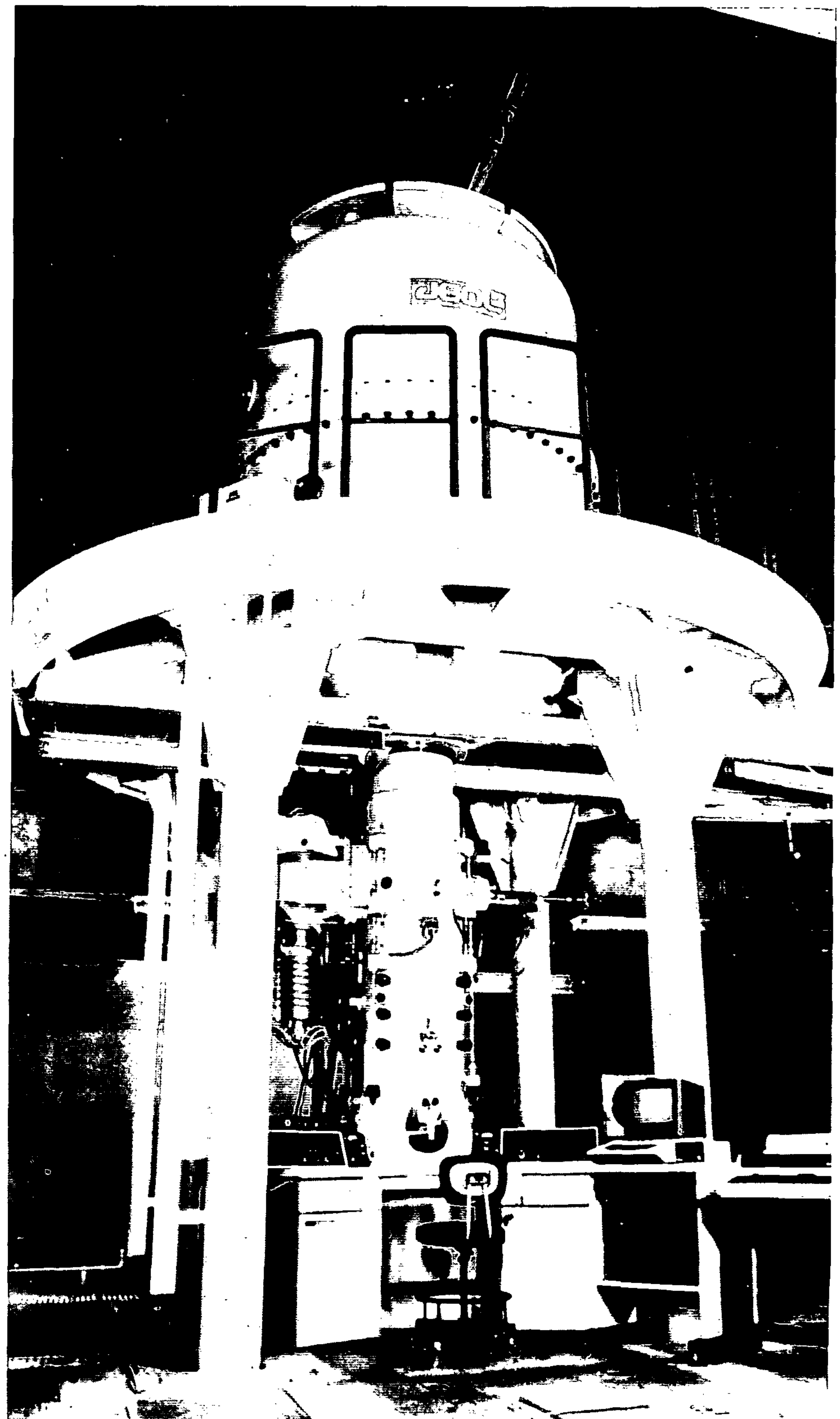
National Center for Electron Microscopy, Lawrence Berkeley Laboratory, Berkeley, California

On September 30, 1983, the National Center for Electron Microscopy (NCEM), which cost $8.0 million dollars, was dedicated. The Center's dedication culminated nearly 9 years of research, development, and construction. NCEM contains the most advanced electron microscopes in the world and has as its centerpiece the only atomic resolution electron microscope (ARM) in the United States. Besides the ARM, other available microscopes are a Hitachi HU-650, Kratos EM-1500, and JEOL 200 CX.

The JEOL JEM-ARM-1000 was specifically designed for ultimate performance in the high-resolution imaging mode. Attention has been given to the potential problem of specimen sensitivity to the electron beam at higher accelerating voltages, and a microprocessor-controlled height variable goniometer has been incorporated so that the microscope will operate with minimum aberration over its entire voltage range (400 to 1000 KeV). At its maximum voltage (1 MeV), the ARM has a point-to-point resolution of 1.7 Å. At higher lens excitation values, the microscope can be run in condenser-objective mode; this enables convergent beam electron diffraction (CBED) patterns to be taken from the same specimen areas imaged in high resolution.

For increased stability, the stage configuration on this machine is top entry, with standard 3-mm-diameter specimen cartridges; it is coupled to a microprocessor for precise stage manipulation. The microscope uses LaB_6 filaments for additional brightness, and the camera accepts 50 film cassettes.

The Kratos EM-1500 High Voltage Electron Microscope is designed primarily for dynamic in-situ studies, but it can also resolve structures at the 3 Å level. It is the first electron microscope with a maximum acceleration voltage of 1.5 MeV to be built by Kratos. As such, it provides accelerating voltages of 1200 to 1500 KeV, which are not available elsewhere in the United States. To achieve the higher accelerating voltage, the number of stages of the Cockcroft-Walton generator was increased to 9 and the SF_6 insulating gas pressure was increased to ~90 psi. Conditioning of the accelerator tube is carried out at 1.6 MeV. The accelerating voltage actually can be set at 150 or 200 to 1500 KeV in 100-KeV increments. The microscope is equipped with both a top-entry stage for high resolution studies and a side-entry stage for general, dynamic in-situ, and environmental cell studies. Several different specimen stage rods are available (see table on p. 22), and this inventory will be increased as needed.



SPECIMEN STAGES FOR EM 1500

Type	X-Tilt	Y-Tilt	Temperature
Double tilt, cartridge type	±45°	±45°	Ambient
Single tilt, cartridge type*		±45°	Ambient
Double tilt, furnace type	±30°	±30°	Ambient to 850
Single tilt, furnace type*		±25°	Ambient to 850

*For use with Environmental Cell at pressures up to 1 atmosphere.

A support instrument to the ARM, the JEM 200-CX is well-known for its high-resolution performance. This machine, which is equipped with an ultrahigh resolution goniometer (top entry), has a maximum operating voltage of 200 KeV with a point-to-point resolution of about 2.4 Å. Specimens for this microscope are restricted to 2.3 mm in diameter to fit into the ultrahigh resolution pole piece.

The fourth microscope at LBL is the Hitachi HU-650. It has an accelerating voltage that is continuously variable between 200 and 650 KeV, but it is calibrated for, and most conveniently used at, three fixed voltages, 300, 500, or 650 KeV.

The resolution limit of this instrument is not high—about 20 Å—but it is adequate for some studies, exploratory experiments, and many hot stage or environmental cell experiments.

High Voltage Electron Microscope-Tandem Facility, Argonne National Laboratory, Argonne, Illinois

The High Voltage Electron Microscope (HVEM)-Tandem Facility is operated as a national materials science resource available to qualified scientists in the United States. The facility provides unique combinations of the techniques of a high-voltage electron microscope, ion implantation/bombardment, and ion-beam analysis. In addition, the HVEM/ion-beam interface permits direct observation of the effects of electron and ion bombardment on materials in the microscope. The ion-beam interface is an instrumental beam transport that connects the 2-MeV tandem and the 300-KeV ion accelerators to the HVEM. Current experimental studies using the HVEM represent a wide range of materials research from universities, national laboratories, and industry. Work includes programs in mechanical properties, corrosion and oxidation, radiation damage, and general defect analysis.

The principal components of the HVEM-Tandem Facility are a Kratos 1.2-MeV high-voltage-transmission electron microscope with ion-beam interface, a National Electrostatics 2-MeV tandem-type universal ion accelerator, and a Texas Nuclear 300-KeV ion accelerator. These two accelerators together provide ion beams of essentially all elements from ~10 KeV to 8 MeV. Contiguous support facilities for the microscope include two darkrooms, a specimen-preparation laboratory, an instrument laboratory, and a preparation laboratory for mechanical work shared with the accelerator facility.

The high-voltage electron microscope is an improved Kratos/AEI-EM7 with a maximum voltage of 1.2 MeV and a demonstrated lattice resolution of 3.5 Å. In addition to a 33° ion-beam access tube, the microscope contains a number of unique features. These include a negative ion trap, an ion-pumped specimen chamber, two independently adjustable dark-field conditions, and a 100 to 1200-KeV continuous-mode voltage selection from the control desk. The electron beam dosimetry system consists of a retractable Faraday cup above the specimen and a movable cup above the fluorescent screen to probe the current density profile of the beam. Special specimen rods for viewing and for measuring the intensity of the ion beam within the microscope also are available. Observations can be made at temperatures between 10 and 130°K in high-vacuum conditions. Observations in gaseous atmospheres at pressures of up to 2.5×10^4 Pa can be carried out between ambient temperature and 1300°K using a gas reaction cell inserted into the specimen chamber. This HVEM is equipped with the Harwell-design camera and has a capacity of 48 plates and a video monitoring and recording system.

The National Electrostatics Type 2UDHS 2.0-MeV Tandem Accelerator is equipped with an internal and two external negative sources for He^- and metal ions, respectively. The machine can generate ions of all stable isotopes in the periodic table. The accelerator can be operated in conjunction with the HVEM or separately for ion implantation/bombardment and ion-beam-analysis studies. Typical ion-beam currents will range from ~10 A for protons to 0.1 μA for $^{204}Pb^+$.

There is also a 300-KeV ion accelerator that has been equipped with sources for metal and gaseous positive ions. This accelerator can be used in conjunction with the ion-beam interface when lower-energy ions are required or to deliver ions into two of the target chambers of the Tandem system for ion implantation studies. The 300-KeV accelerator cannot be used when ions from the Tandem are passed into the ion-beam interface.

Shared Research Equipment Program, Oak Ridge National Laboratory, Oak Ridge, Tennessee

The Shared Research Equipment program (SHaRE) is a collaborative program in which personnel at Oak Ridge National Laboratory work with scientists from other institutions. It is the third facility having an HVEM. The purposes of the program are to provide university and industrial researchers with access to equipment for microstructural analysis which is not available at their home institutions and, in so doing, to facilitate additional laboratory research that would not otherwise be accomplished. The laboratory staff shares with visitors responsibility for both completing the project and ensuring publication of the results.

A number of major instruments are available to collaborators. Nuclear microanalysis and Rutherford backscattering analysis are performed in two separate systems, and four variously equipped 120-KeV transmission electron microscopes are in service. A Hitachi 1-MeV HVEM is equipped for environmental and mechanical deformation investigations. Two Auger analysis systems, one with scanning capability, also belong to the equipment pool in the SHaRE program.

Oak Ridge Electron Linear Accelerator

Oak Ridge National Laboratory, Oak Ridge, Tennessee

The Oak Ridge Electron Linear Accelerator (ORELA), a facility of continuing importance in the development of fission and fusion energy technologies, is used for measurements of neutron cross sections over a whole range of thermal energies, from 0.02 eV to 80 MeV. These cross sections are needed to design and operate nuclear fusion and fission power reactors and to study some aspects of nuclear reaction mechanisms and nuclear structure. At present cross sections are best measured by repetitive, intense neutron pulses and the short-burst performance of ORELA. Energy-dependent neutron cross section and related measurements of almost every variety are made with this facility. The ORELA was upgraded several years ago with a new electron gun and klystron prebunching system to increase the effective neutron output.

The ORELA, which was built in 1969 at a cost of $10 million, provides 22 A peak currents of 100- to 170-MeV electrons at burst widths from 3 to 24 nsec at the rate of 25 to 1200 pulses/sec. The electrons impinge on a target material producing the desired neutrons. At an average power of 50 kW, 10^{14} neutrons/sec, time averaged, or 4×10^{18} neutrons/sec, peak, are produced. The design of ORELA, which includes eleven flight paths radiating from an evacuated target room, makes possible simultaneous use by many experimenters, a feature that greatly increses the total output and cost-effectiveness of the facility.

5-MeV Dynamitron Accelerator

Argonne National Laboratory, Argonne, Illinois

The Argonne Dynamitron accelerator provides intense, highly collimated direct-current beams of fast atomic or molecular ionic projectiles for use in experiments in atomic physics, nuclear research, and the irradiation of materials. In operation since 1968, it has been steadily improved over the years. It is a powerful, versatile, and reliable facility that also includes computer systems for control and data acquisition.

Present applications of the accelerator include studies of the interactions of fast molecular ions with matter, determination of molecular ion structures, beam-foil spectroscopy, and ion channeling in crystals. Nuclear research includes weak interaction studies, measurements of parity violation in nuclei, quark searches, and measurements of the cross section for reactions between light nuclei. The materials research is centered on damage studies related to the first-wall problem in fusion reactors.

A valuable feature of the machine is that a broad range of positive-ion projectile species can be accelerated and analyzed magnetically. There are six fully instrumented beam lines, including one with a unique capability for experiments requiring extremely high angular resolution and one equipped for simultaneous dual-beam irradiations with a magnetically analyzed beam from a neighboring 20-MeV Van de Graaff accelerator merged with the Dynamitron beam. The accelerator voltage can be varied smoothly between 0.3 and 5.0 MeV. Monatomic positive-ion beams of most of the elements are readily produced, as are molecular-ion beams, including such complex projectiles as $C_6H_6^+$. Most beams are available at the microampere level, and some (e.g., hydrogen and deuterium beams) at the milliampere level, continuously or in a pulsed mode down to a few tenths of a nanosecond and at repetition rates variable up to 8 MHz.

Calutrons—Electromagnetic Isotope Separations Facility

Oak Ridge National Laboratory, Oak Ridge, Tennessee

The electromagnetic isotope separations facility at Oak Ridge National Laboratory (ORNL) enriches stable isotopes, selected radioactive isotopes, and heavy-element isotopes for use in research and development and in commercial activities. It consists of very high current mass separators, known as Calutrons, which were originally designed and built under the Manhattan Project during World War II. The Calutron facility is a unique national asset; the USSR is the only other nation possessing such a facility. Many other countries have laboratories in which isotopes are enriched, but these facilities are usually of limited size and the isotopes are used for specific purposes. Research and development directed toward increasing both the throughput and the isotopic purity of the products is also conducted at ORNL. The Isotope Sales Office distributes the isotopes in two ways: Multigram quantities of enriched samples from the Research Materials Collection are loaned to members of the DOE research community at a nominal fee for nondestructive research, and enriched isotopes are sold to other research and commercial organizations on a cost-recovery basis.

The facility consists of two "tracks" containing 62 separator tanks. Eight tanks are reserved for chemically hazardous and radioactive elements and 44 for stable isotopes. Of these, 30 comprise the stable isotope track. The remaining ten tanks can be used to separate either radioactive or stable isotopes. The horizontal magnetic field of the stable isotope track is subdivided into four segments by magnetic shunts that extend from one side of the track to the other. The resulting three banks of eight separators and one bank of six separators can be used independently. If the magnetic field in each separate segment is excited, it is theoretically possible to enrich the isotopes of four elements simultaneously in the 30 Calutrons. A recent operational improvement has established that, for cases where the isotopic mass ranges of several elements overlap, the isotopes of these elements can be separated simultaneously in one magnetic segment.

When feed material, in either elemental or compound form, is introduced into a Calutron, it is either directly vaporized or heated with chemical treatment to form a volatile species. This vapor is then introduced into an arc discharge, where it is ionized in the high-current source. The ionized particle is extracted from the ion source, accelerated, and magnetically focused. The focused individual isotopic beams are intercepted by collectors constructed of carbon, copper, or aluminum. After a run, the duration of which may be fifty to several hundred hours depending on the element, the collectors are removed from the separator, and the material is extracted, chemically purified, assayed, and placed in the inventory.

Since each element or compound has unique operating characteristics, it is difficult to generalize about the throughput capability of the facility. Typical beam currents are between 10 and 100 mA, with an average of 25 to 50 mA. As a rule of thumb, one separator can provide approximately 0.1 mole of an element per day of operation. This figure is multiplied by the natural isotopic abundance to determine the yield for a particular isotope. Isotopic purity depends on the natural isotopic abundance of the isotope required and the abundance of its nearest neighbors. The products of one separation can be recycled to obtain a significantly higher isotopic assay in a two-pass process.

Materials are available from the Research Materials Collection (RMC) for loan to U. S. scientists for use in nondestructive experiments and to non-U. S. scientists under restrictive conditions (e.g., the experiment must be of direct relevance to the DOE technology programs, such as the use of RMC samples within the European community for the study of neutron cross sections). Such loans are usually made only on the strong recommendation of the U. S. Nuclear Data Committee.

Materials are sold from the sales inventory to anyone on a first-come, first-served basis. Up-to-date information on the electromagnetically enriched isotopes, their chemical form, percent enrichment, price per milligram, and availability can be obtained from E. Newman, Operations Division, ORNL, P. O. Box X, Oak Ridge, TN 37830.

Transuranium Processing Plant

Oak Ridge National Laboratory, Oak Ridge, Tennessee

The Transuranium Processing Plant (TRU) was built to recover radioactive transuranium elements from irradiated targets and to serve other chemical processing and fabrication needs of the Transplutonium Production Program of the Atomic Energy Commission. It is not a research facility for BES, but it provides unique chemical processing capabilities for highly radioactive actinide materials. Research in nuclear chemistry and physics and nuclear technology, especially as related to fission energy development and to fundamental behavior of the actinide radionuclides that pose significant problems in nuclear waste treatment and isolation, is supported by TRU activities. A nuclear energy program "user" group currently in residence at TRU operates the Solvent Extraction Test Facility, which is part of the ORNL Consolidated Fuel Reprocessing Program.

Samples ranging from hundreds of grams of curium-244 to picograms (10^{-12}) of fermium-257 have been provided by TRU, and research quantities of a variety of transuranium isotopes prepared at TRU have contributed to our understanding of the chemical, physical, and nuclear properties of the actinide elements.

The TRU, built at a cost of $8.8 million, began "hot" operation in 1966. It contains seven hot cells, each equipped to carry out remotely one or more separate procedures for chemical separation, purification, fabrication, or analysis of highly radioactive materials.

In addition to its use for the nuclear energy program's solvent extraction research and development, the facility also contributes to DOE's isotope production and sales activities.

Program and Budget Trends

Basic Energy Sciences (BES), as the program responsible for fundamental, longer term, research supportive of the mission of the Department of Energy, is committed to continuing studies in the physical and related sciences. It has funded and conducted creative research programs and managed complex facilities for DOE and its predecessor organizations since the 1940s, a period of unparalleled scientific growth and achievement.

Basic Energy Sciences long range research complements and undergirds the applied research and development activities of DOE's technology programs. The BES program is not likely to advance DOE's short-term goals, nor is it supposed to. Its major product is fundamental knowledge relevant to energy exploration, production, conversion and use. This new knowledge becomes part of the body of information upon which the applied technologies rest. While research to broaden the technology base needed for identified energy technology options is extremely important, even more important, to constantly improve our science base, is our need for basic research unfettered by preconceived notions of what technologies will be important several decades from now. It is from such basic research and its generation of new ideas and concepts that new, currently unidentified options may emerge.

Basic Research is a necessary investment in the future and continuous, uninterrupted research programs are invaluable to the nation in providing a knowledge base on which to build. Because of its experience, diversity, and unique capabilities, BES continues to be able to respond to growth and new directions in national goals and missions.

During the decade from 1973 to 1983, BES experienced a significant expansion in its research responsibilities to include knowledge required by non-nuclear energy technologies. Towards the end of this period, several major construction projects were reaching fruition and the BES budget growth rate increased, primarily to meet the special needs associated with the operation of the newer facilities and for new construction projects. The budget for FY 1984 is approximately $350 million (Table 1) of which $24.3 million, about 7%, is for capital equipment, and the fraction of the FY 1984 budget appropriation designated for construction rose to 5%.

Table 1 Office of Basic Energy Sciences Budget

	FY 1983 10^6 dollars	FY 1984 10^6 dollars	FY 1985 10^6 dollars
Operating Expenses (by subprogram)			
Materials Sciences	108.2	125.1	133
Chemical Sciences	70	75.5	79.5
Nuclear Sciences	30.6	37.9	40.3
Applied Mathematical Sciences	13.9	14.7	35.1
Engineering and Geosciences	17.2	19	26.7
Advanced Energy Projects	8.3	9.1	10.6
Biological Energy Reseach	9.5	10.6	12.5
Carbon Dioxide Research	9.1	12.5	13.4
Program Direction	3.2	4	3.8
Subtotal	270	308.4	354.9
Capital Equipment	18.2	24.3	31.1
Construction	3.4	17.2	50
Total	291.6	349.9	436

Some changes in responsibility occurred during FY 1984. The Division of Engineering, Mathematical, and Geosciences was restructured with the Applied Mathematics Sciences management responsibility being transferred to a newly formed office under a director of Scientific Computing. The budget for Applied Mathematical Sciences continues to be under BES.*

*Information on the Applied Mathematical Sciences is available from Dr. James F. Decker, Director of Scientific Computing, ER-7, Office of Energy Research, DOE, Washington, D. C. 20845.

Research support for Heavy Ion Fusion Research which previously had been conducted under the Defense Program was included in the Nuclear Sciences subprogram at a level of $5 million. Also in FY 1984, several new construction projects were undertaken, one for facilities at LBL to comprise a new Center for Advanced Materials Research, and two others, at the initiative of the Congress, to provide updated, modern buildings for research on university campuses.

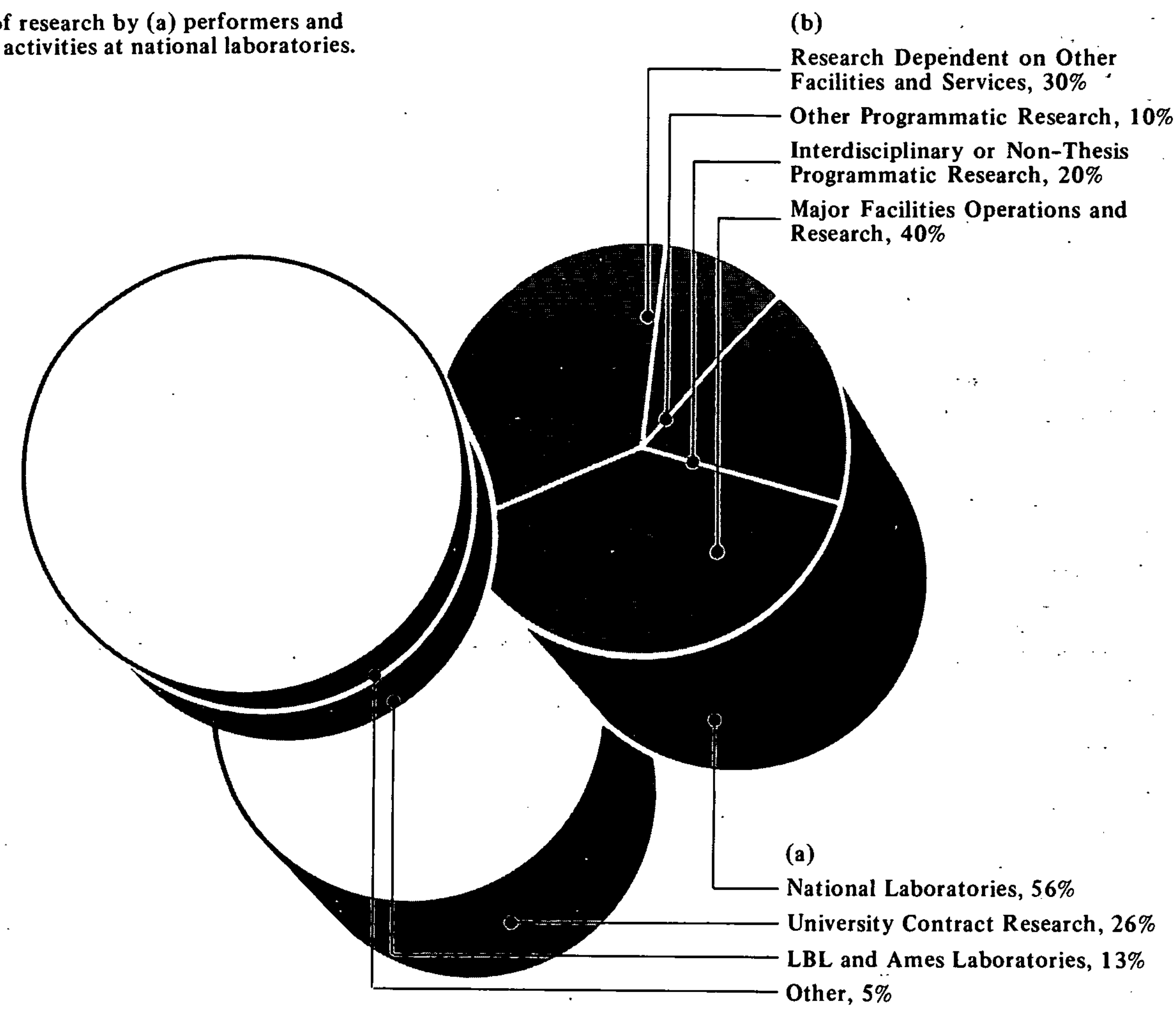
Figure 3 presents a breakdown identifying the major performers who carry out the Basic Energy Sciences program. About 69% of the program is conducted at the national laboratories including Lawrence Berkeley Laboratory (LBL) and Ames Laboratory, 26% at universities throughout the country, and the remainder elsewhere, including nonprofit institutions and industry. Plans are to maintain the university portion of the program at about 26%, not including Ames Laboratory and Lawrence Berkeley Laboratory. These two major laboratories, which are colocated with universities (Lawrence Berkeley at the University of California, Berkeley, and Ames at Iowa State University), receive almost one-fifth of the BES support going to national laboratories. If they are included with the universities, that portion of the program rises to 39%, with a corresponding decrease under national laboratories. The research supported by BES at Ames and LBL is conducted almost entirely by faculty members and graduate and postdoctoral students.

Of the funding going to national laboratories, about 90% is for activities uniquely dependent on the facilities and services at the specific laboratories supported. The operation of major scientific facilities continues to require a large commitment of BES funds. Operating costs for facilities for FY 1984, exclusive of the costs of research done at the facilities, are projected at $55 million; they are expected to rise to nearly $70 million in FY 1985.

The future for BES continues to be more and more challenging as the frontiers of science expand. Current trends are toward greater use of the major facilities, by both DOE and "outside" researchers, and strengthening of research in the areas of science dealing with:

- Surfaces—modification, interfaces, reactions at surfaces
- Solids—properties and structure, including grain boundaries, condensed matter theory, atomic transport, amorphous materials, structural ceramics
- Plants—genetics, response to stress, photochemistry
- Geothermal energy resources—occurrence, characterization, chemical and thermal properties
- Multiphase systems—transport properties, chemical behavior, etc.

Figure 3 Breakdown of research by (a) performers and (b) nature of research activities at national laboratories.



Experiments with, for example, phenomena involving extremely short time periods, vanishingly small concentrations of reacting species, entities with only transient existence, and measurements under extreme conditions of temperature and pressure point out the necessity for constantly improving equipment. Examples of BES's efforts to meet these kinds of challenges include the new Atomic Resolution Microscope which came on line in 1983, and the ever increasing efforts to exploit synchrotron radiation and advanced neutron sources to increase our understanding of the atomic structure of materials.

Despite increasing costs and demands for constantly improved equipment and installations, the unique research programs and facilities supported by BES must be maintained, improved and expanded. The knowledge base they create is vital to improving or developing new energy technologies.

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