OAK RIDGE NATIONAL LABORATORY

INSTITUTIONAL PLAN

ORNL/PPA-90/3

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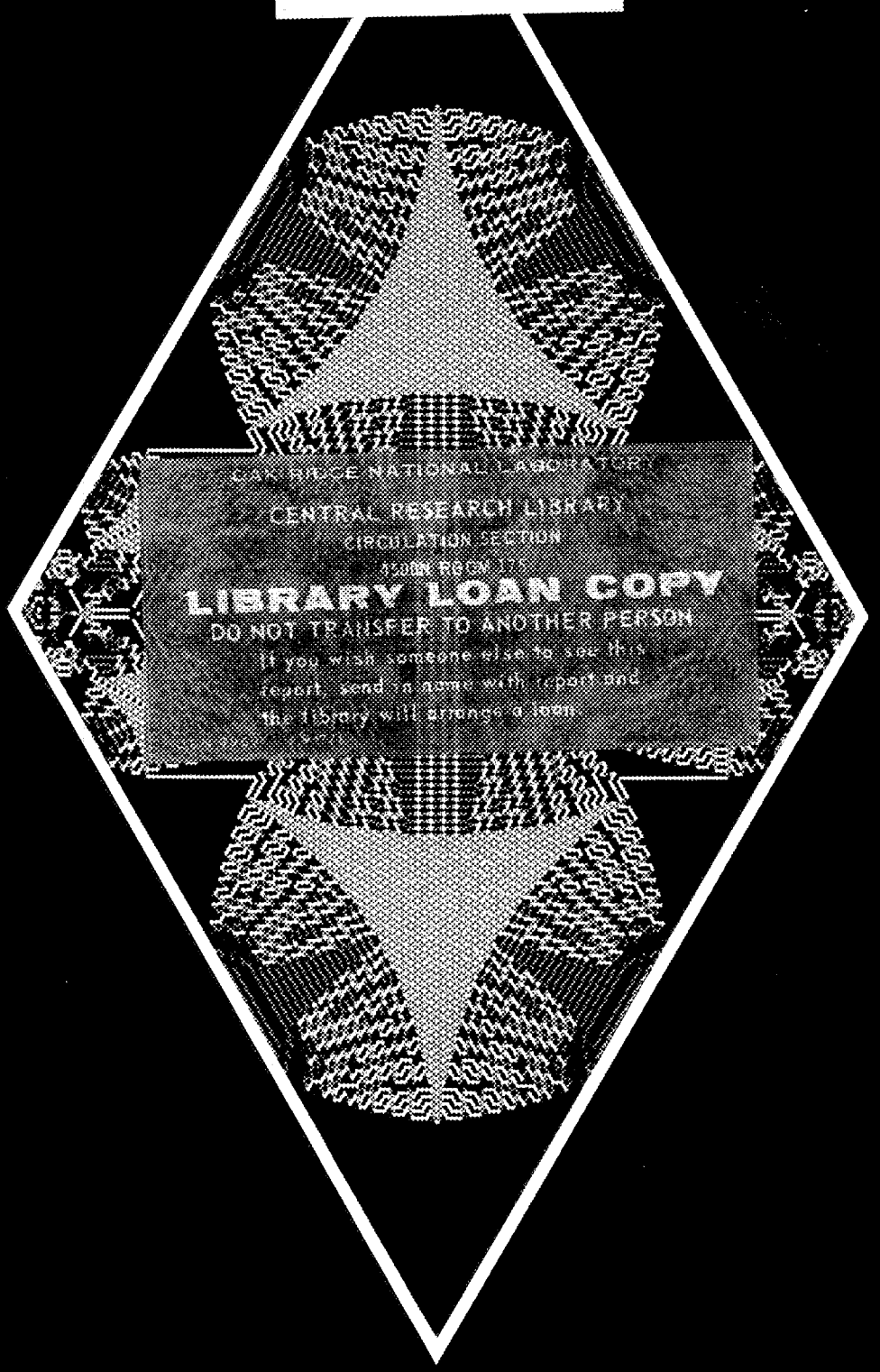

FY 1991–1996

ORNL/PPA-90/3

Oak Ridge National Laboratory Institutional Plan

FY 1991–FY 1996

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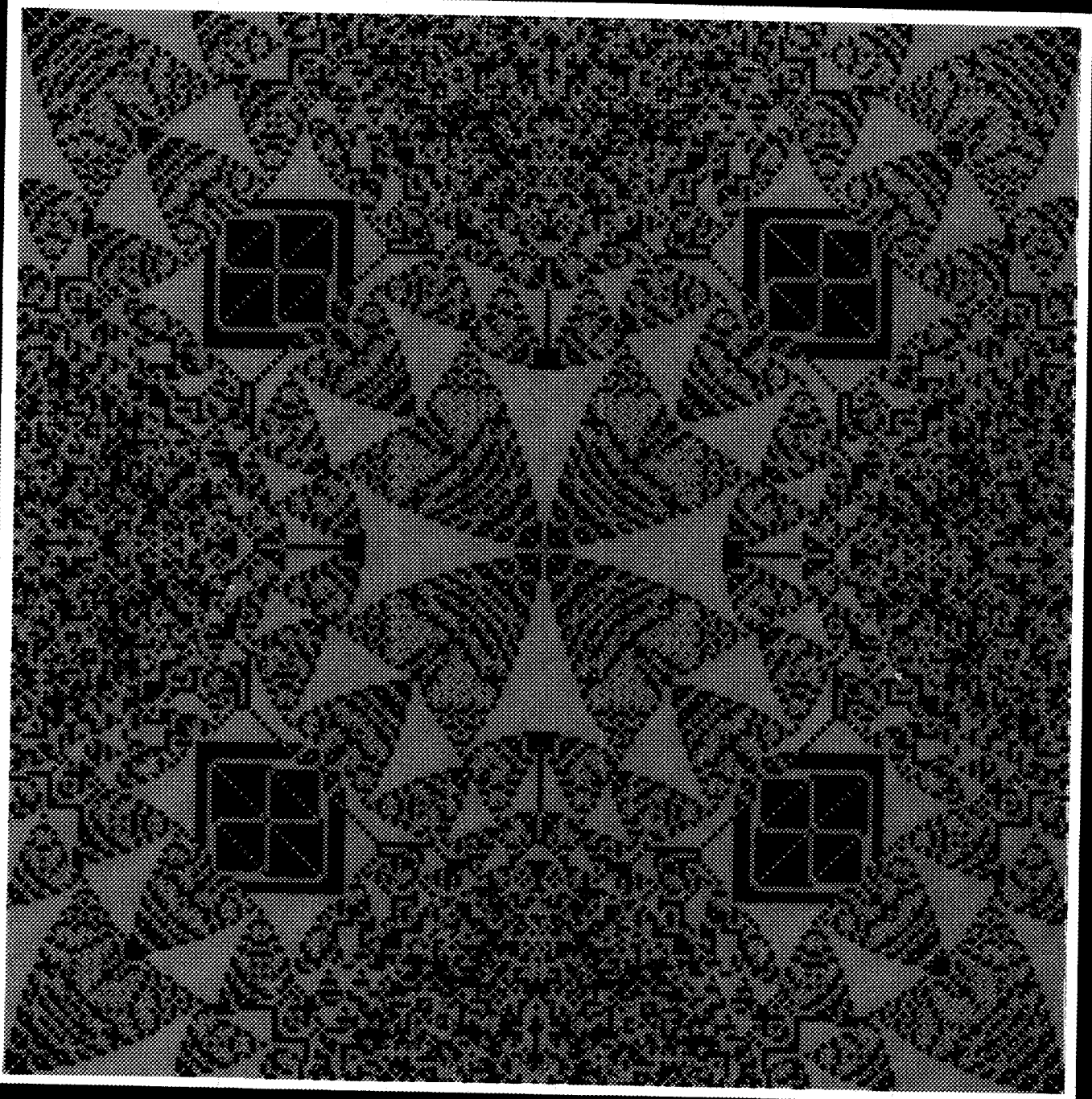
Laboratory Director's Statement



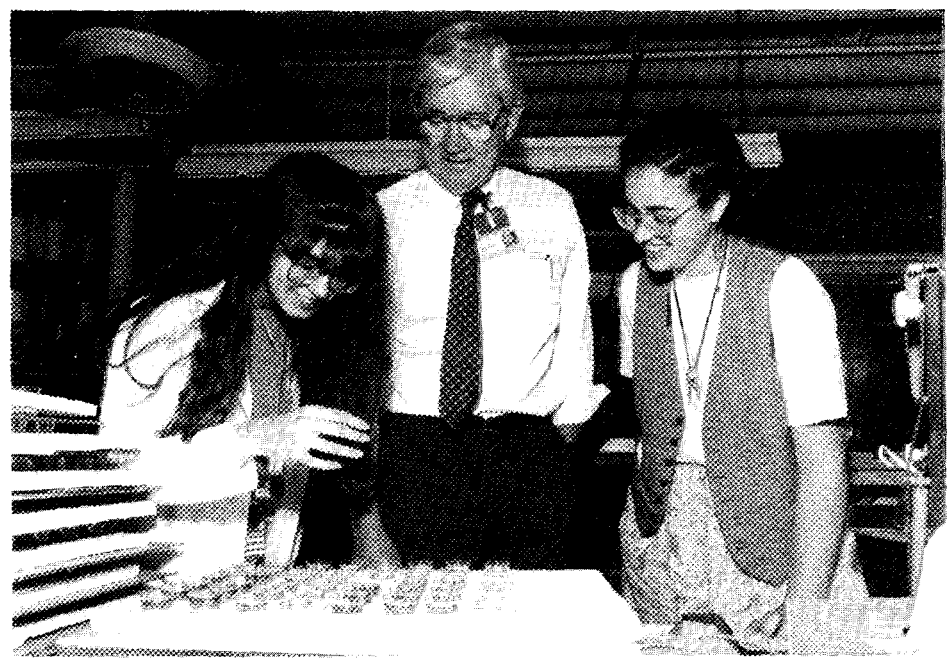
Laboratory Director's Statement

More than most years, 1990 was one of challenge and change for ORNL and, indeed, for much of the world. In cities and communities from Eastern Europe to the Amazon rain forest, environmental protection took on a new sense of urgency. The conflict in the Middle East underscored for nations everywhere the consequences of energy dependency. Slipping competitiveness in the global marketplace encouraged this country to put education back on the agenda of national priorities. And the Tiger Team visit here at ORNL served as a reminder that our R&D activities must be conducted with keen sensitivity to the environment and to the health and safety of our work force.

The challenges we face as a nation and, by extension, as a national laboratory are enormous. However, I have confidence in our ability to meet these challenges because I know first-hand the caliber and scope of our intellectual resources. I know that we will do whatever it takes to be the best at whatever we do.

Since launching the emergency wartime Manhattan Project in the 1940s, the U.S. government has established a network of laboratories that represents one of the most impressive assemblies of scientific brainpower the world has ever known. And while specific priorities have changed during periods of war and peace, the DOE laboratories remain uniquely capable of mobilizing to address pressing technological challenges as they arise.

Within this network, ORNL occupies a special niche as the largest of DOE's nonweapons facilities. And as such, ORNL is uniquely equipped to contribute to the national interest,



Laboratory Director Alvin Trivelpiece watches as two participants in the High School Honors Workshop perform testing experiments in an Environmental Sciences Division laboratory. This program is one of the many educational programs at the Laboratory designed to encourage scientific interest among students.

particularly in the arenas of energy, environment, education, and economic competitiveness.

We are continuing to work, for example, on the development of viable new energy technologies and methods to conserve existing resources. ORNL research continues on advancing such promising energy sources as biomass and fusion as well as developing fission and fossil technologies. In addition, we are investigating ways that we can contribute to building the nation's much-heralded superconducting super collider. Having created the Oak Ridge Detector Center over a year ago, we are collaborating with several universities in seeking to construct two of the facility's three massive particle detectors.

We are also exploring crucial environmental issues on a national and international level through the ORNL Center for Global Environmental Studies. Notable for its interdisciplinary strength, scientists at the center are conducting a comprehensive research program on such complex phenomena as global warming, ozone depletion, and acid rain. We are additionally pursuing solutions to the serious problem of nuclear and hazardous waste cleanup at our own facilities and DOE facilities across the country. Including both basic and applied R&D, our waste R&D initiatives are designed to analyze the conditions necessary for successful environmental restoration, develop new cleanup technologies, recommend processes and procedures for future waste management, and transfer appropriate technology to the private sector.

This emphasis on technology transfer is indicative of the high priority we place on sharpening U.S. competitiveness. Our technology transfer program is designed to ensure that appropriate ORNL technologies are transferred to the private sector where they can be used to make the nation competitive in the global marketplace. The 36 licenses granted since we created the Office of Technology Applications in 1985 have enabled U.S.-based manufacturers to generate over $20 million in product sales and $750,000 in royalties. We also operate a dozen unique research facilities for the benefit of scientists from universities, industry, and other research facilities. ORNL currently hosts more than 2300 guest researchers a year, and that number is expected to double by the turn of the century. Among our most exciting initiatives is the establishment over the next decade of the Advanced Neutron Source—the world's most powerful research reactor—which will accommodate 900 more users.

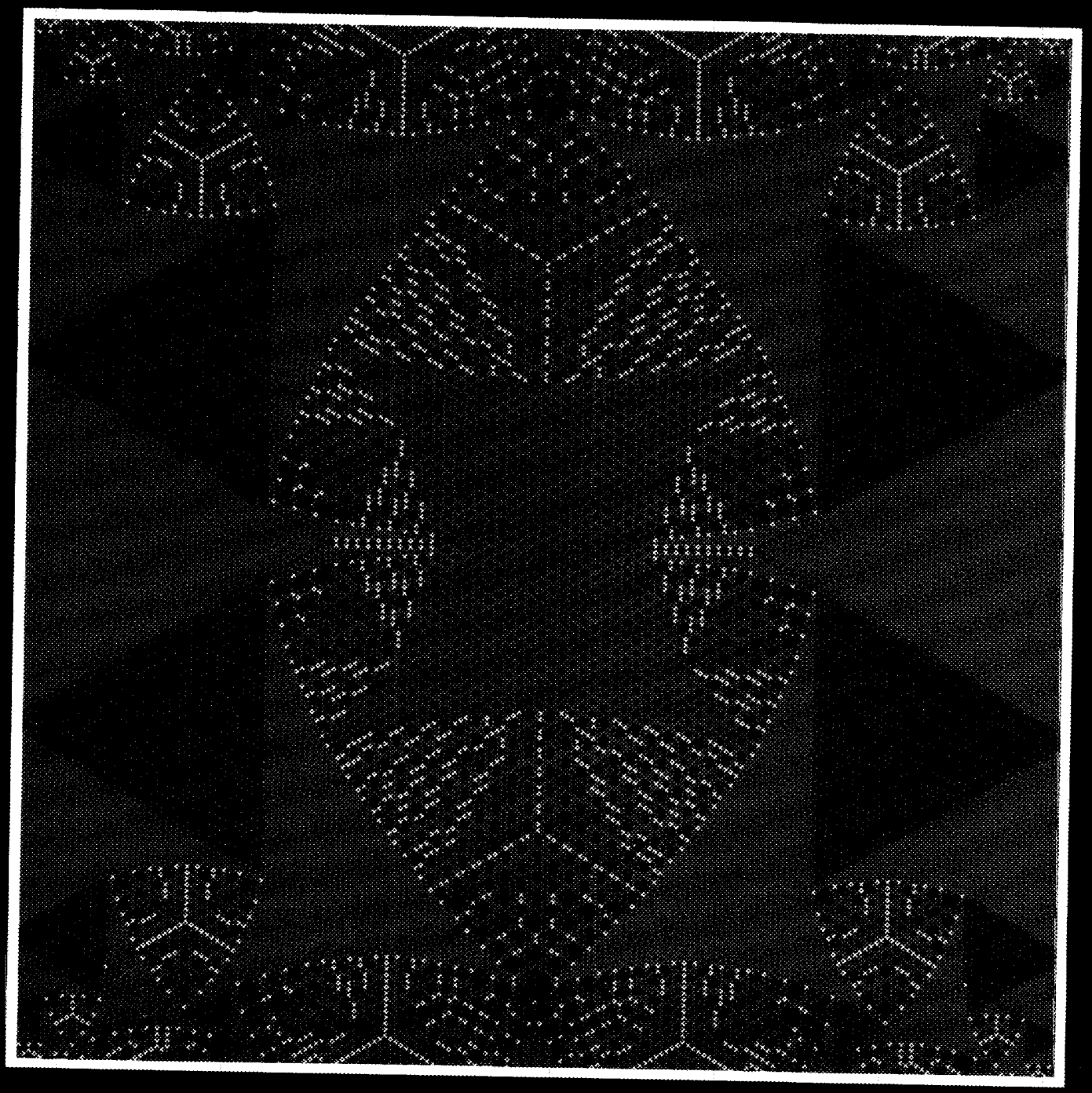
Of course, a genuine competitive edge for our nation will result not from just one factor, such as technology transfer, but from a combination of conditions. Principal among these conditions is a work force prepared for the economy of the 21st century. For this reason, we are dedicated to promoting scholastic excellence in science and mathematics. In addition to conducting a variety of education programs that attracted some 16,000 students last year, we have been asked by the National Science Foundation to lead a new nationwide science-workshop program for teachers of grades K–8.

Intrinsic to success in many of these broad program areas is a strong materials science program and a high priority on basic research. Maintaining a sound investment in basic sciences is essential for ORNL and the other multiprogram laboratories to continue producing the types of research results that serve the nation well.

Given the scope and complexity of our work, the institutional planning process is a necessary vehicle for establishing goals, deciding priorities, and refining approaches. The Institutional Plan that emerges from this process is the map that provides the direction to the full spectrum of ORNL activity.

Our plans are ambitious. But given the breadth of expertise and the dedication of the staff at the Laboratory, I know that we can build on our past achievements and continue to make critical contributions to the national interest.

Laboratory Missions



Laboratory Missions

The Oak Ridge National Laboratory—one of DOE's major multiprogram laboratories—focuses its resources on energy research and development (R&D) but also applies its expertise and facilities to other R&D challenges that are important to DOE and the nation (Fig. 1). To be able to meet these R&D challenges, the Laboratory must achieve excellence in its operations relative to environmental, safety, and health (ES&H) protection and to restore its aging facility infrastructure. ORNL's missions are carried out in compliance with all applicable ES&H regulations.

- **Energy Technologies**—The Laboratory conducts applied R&D in energy technologies—in conservation (i.e., more efficient energy conversion and use); fission; magnetic fusion; health and environmental protection; waste management; renewable resources (biomass and hydro); and fossil energy.

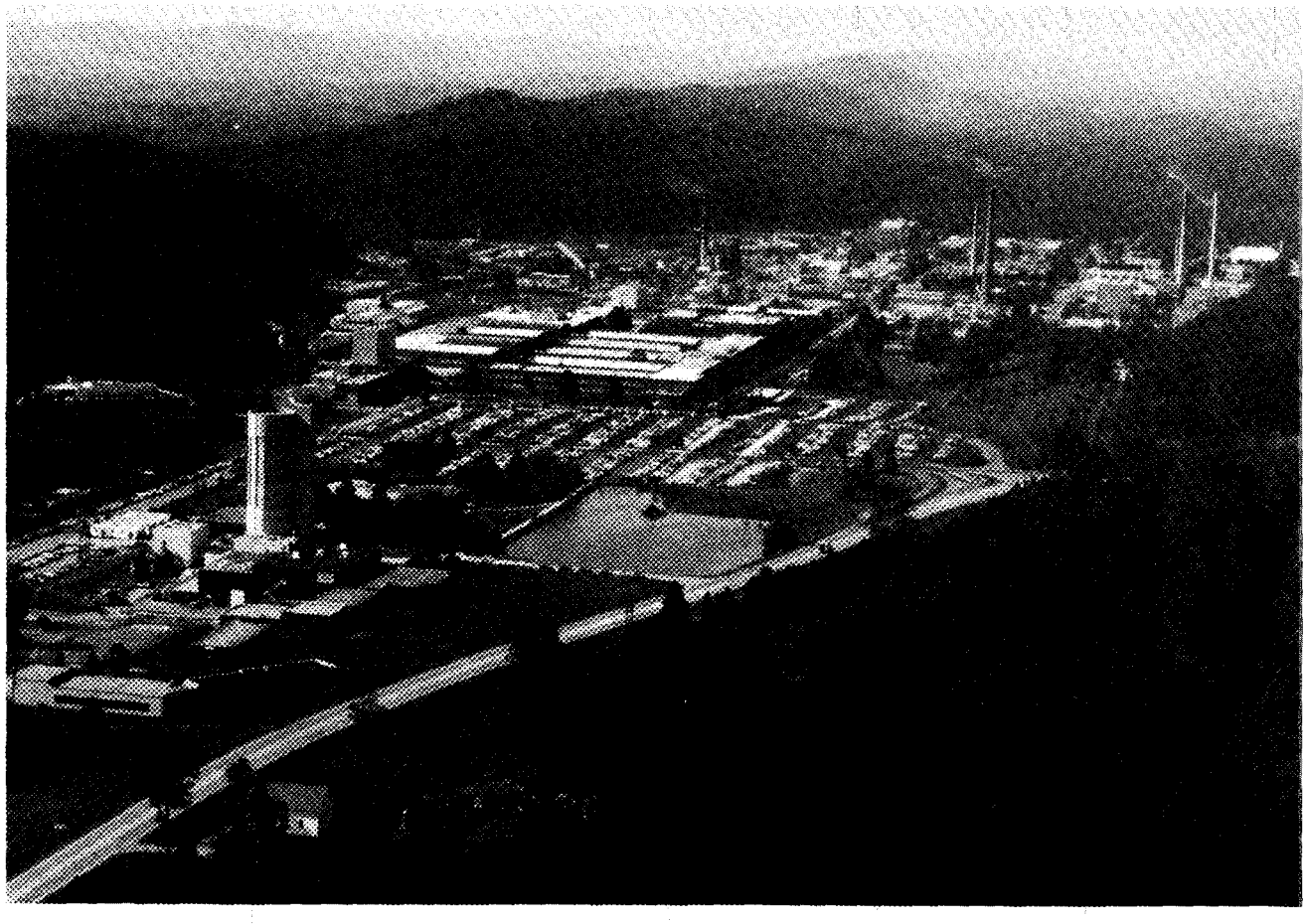
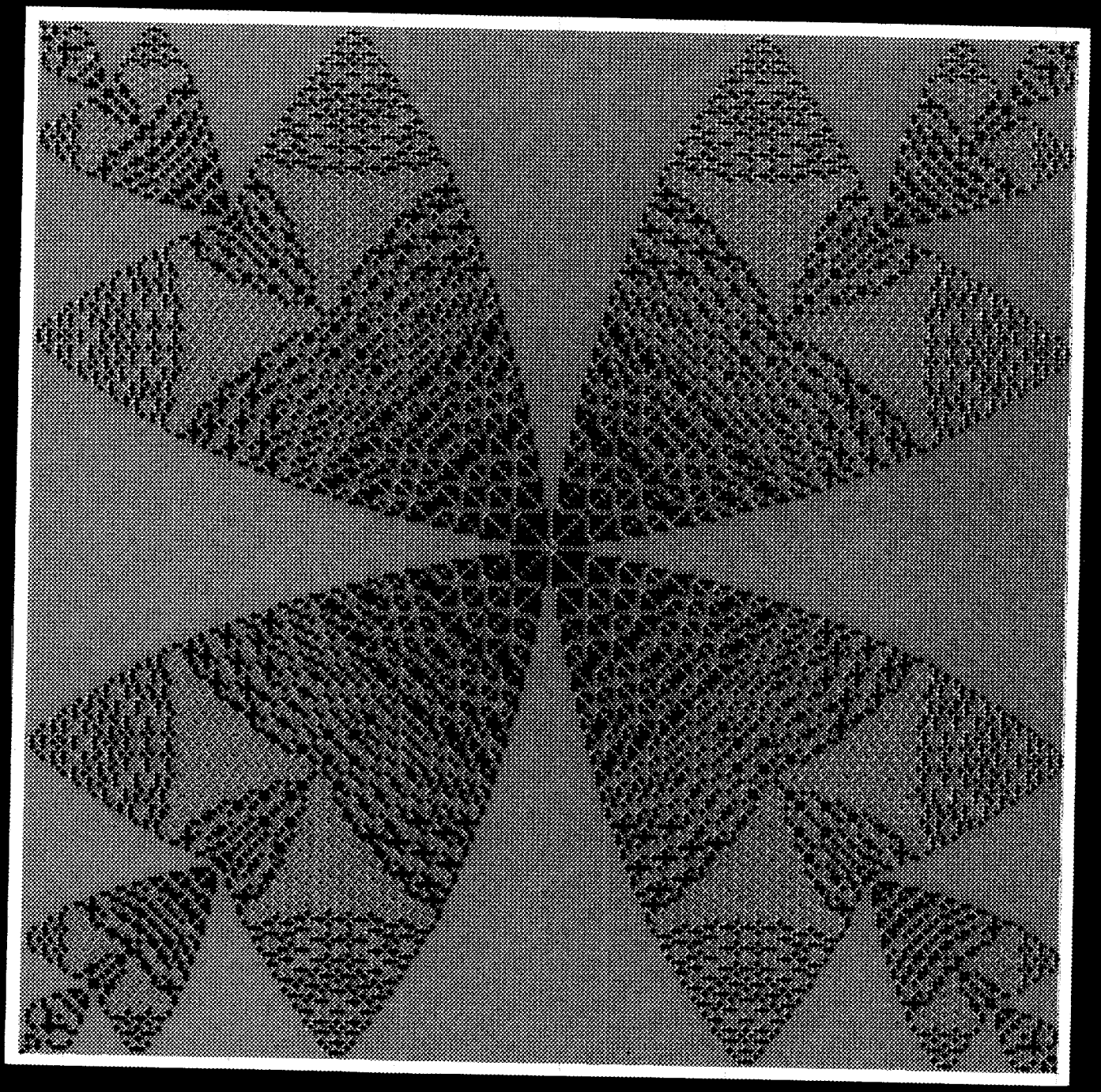


Fig. 1. An aerial view of the Oak Ridge National Laboratory.

- **Basic Research**—Experimental and theoretical research is undertaken to investigate fundamental problems in physical, chemical, materials, computational, biomedical, earth, and environmental sciences; to advance scientific knowledge; and to support energy technology R&D.
- **National R&D User Facilities**—ORNL designs, builds, and operates unique research facilities for the benefit of university, industrial, and national laboratory researchers. The Laboratory serves as a catalyst in bringing national and international research elements together for important scientific and technical collaborations.
- **Education**—ORNL helps to prepare the scientific and technical work force of the future by offering innovative and varied learning and R&D experiences at the Laboratory for students and faculty from preschool level through postdoctoral candidates and by establishing new relationships (partnerships) with educational institutions from elementary schools to universities.
- **Science and Technology Transfer**—The transfer of science and technology to U.S. industries and universities, a key factor in increasing the nation's international competitiveness, is an integral component of ORNL's R&D missions.

ORNL also undertakes research and development for non-DOE sponsors when such work is synergistic with DOE missions.

Laboratory Strategic View



Laboratory Strategic View

The Oak Ridge National Laboratory is one of the major multiprogram laboratories owned by the Department of Energy. The DOE laboratory system has served the department and the nation well in the past, and the future would seem to be no exception. These laboratories contain the largest collection of scientific talent and research facilities in the country, if not the world. This scientific power is essential to the United States in meeting the challenges we face in the next few years. These challenges fall into three categories—energy, environment, and competitiveness. ORNL has strong capabilities and will continue to be a major contributor in all of these areas. The nature of these contributions over the next 15 years is the focus of the following strategic look to the future.

Planning Assumptions

The current situation in the Middle East has renewed the nation's interest in energy. Once again energy has become a grave national concern. In response, energy research and development (R&D) funding may receive a boost over the next few years. Over the next 15 years, energy will continue to grow in importance in the United States and worldwide. First, the world's largest reserves of oil lie in one of the world's most politically unstable regions; this situation is unlikely to change in the foreseeable future. Next, global energy production and consumption will continue to rise; this increase will, in the main, be driven by the developing countries. The impacts this will have on energy prices and the environment will focus attention on improved efficiency and on nonfossil energy supply and use technologies. So far as the United States is concerned, we are faced with falling reserves of gas and oil, increased oil imports, higher energy prices, and a shortfall in electric capacity by the mid-1990s. If our system is a rational one, the above factors will add up to increased emphasis on energy R&D by DOE and its national laboratories. Because ORNL is DOE's largest energy research laboratory, we are in a good position to make major contributions to DOE's programs in energy R&D.

As world population increases, and as this population becomes more affluent, the potential for global environmental change grows ever larger. Presently, global warming and ozone layer depletion are the more visible environmental concerns. Yet, these are only examples of the broader environmental implications of a growing world economy. It is very likely that global environmental issues will become even more important in the future. It is important to note that unless we improve our knowledge base concerning global environmental processes we will be ill-prepared to develop and implement national and international policies to deal effectively with the environmental problems. Much more fundamental research is required if we are to have the understanding needed for intelligent responses to environmental issues. DOE's laboratory system is an important key to gaining this knowledge. Because ORNL's environmental capabilities are among the nation's best, we are in a good position to make major contributions to mankind's understanding of the global environment.

A major revolution is occurring in the biological sciences. ORNL's historic leadership in mammalian genetics and molecular biology will continue with major contributions to understanding the mammalian genome and the genetic basis of human disease. ORNL's research in protein engineering and structural biology will expand and

assume increasing national importance with the construction of the Advanced Neutron Source (ANS).

The international competitiveness issue is one of the most pressing problems facing this country. It is not just a passing fad. It is a structural problem with large scientific and technical components and with no quick fixes. Many things need to be done. We need to strengthen our educational system with special emphasis on scientific and technical education. We need to continue to replenish our reservoir of basic scientific knowledge. And we need to do a better job in helping American industry translate the new knowledge into commercially useful products and processes. Secretary of Energy Admiral James D. Watkins has directed that the national laboratories take on the mission of helping the United States become more competitive through technology transfer and through contributions to scientific and technical education. In some ways, this challenge is more difficult than the Manhattan Project, which birthed the national laboratories nearly a half century ago. It is difficult because it requires fundamental changes in the relationships of government, industries, and universities. In particular, the traditional sharp boundary between industry and government will need to be altered as it becomes evident that the nation must call upon all of its intellectual resources—universities, industries, and national laboratories—to work together toward a common goal.

Although R&D can address many of the important issues facing the nation, there will be significant funding constraints for research. The federal deficit will continue to dampen new initiatives, and competition for research funds will increase. Because of cutbacks in defense spending, many of the defense R&D institutions will become stronger competitors for the civilian R&D dollar. DOE's environmental and waste problems will continue for a decade or more, and funding to address these issues will decrease resources available for R&D. The budget constraints will focus attention on the efficiency and effectiveness of DOE's laboratory system. Big science projects—the Superconducting Super Collider and the ANS—will come under increasing scrutiny. In attempts to cut spending, there may be pressures on DOE to consolidate facilities. Any facility or program that consumes resources and does not produce significant scientific or technological advances will be at risk.

Program Trends at ORNL

The next two decades promise to be a most productive and exciting period in the history of the Laboratory. It will be a period of revolutionary changes in almost every area of science and technology in which ORNL is involved. It will also be a period of considerable challenge. Reflecting national needs, the ORNL environment will be dominated by three major themes—energy, environment, and competitiveness.

Contributions to Competitiveness

Because of the competitiveness mission, collaborative research, centered around major user facilities, will become a very important component of the Laboratory's intellectual output. ORNL currently hosts over 2300 guest researchers each year; by the turn of the century, we expect that number to double. Much of the increase in collaboration with outside researchers will be associated with the expansion of our existing user facilities (Fig. 2) and the addition of new facilities. Major new user facilities we hope to put in operation over the next decade include the world's most powerful research reactor, the ANS; the Center for Biological Sciences; the Materials Science and Engineering Complex; and the Advanced Control Test Operation facility. The ANS alone will accommodate 900 users.

As another element of the competitiveness mission, the Laboratory will expand its already

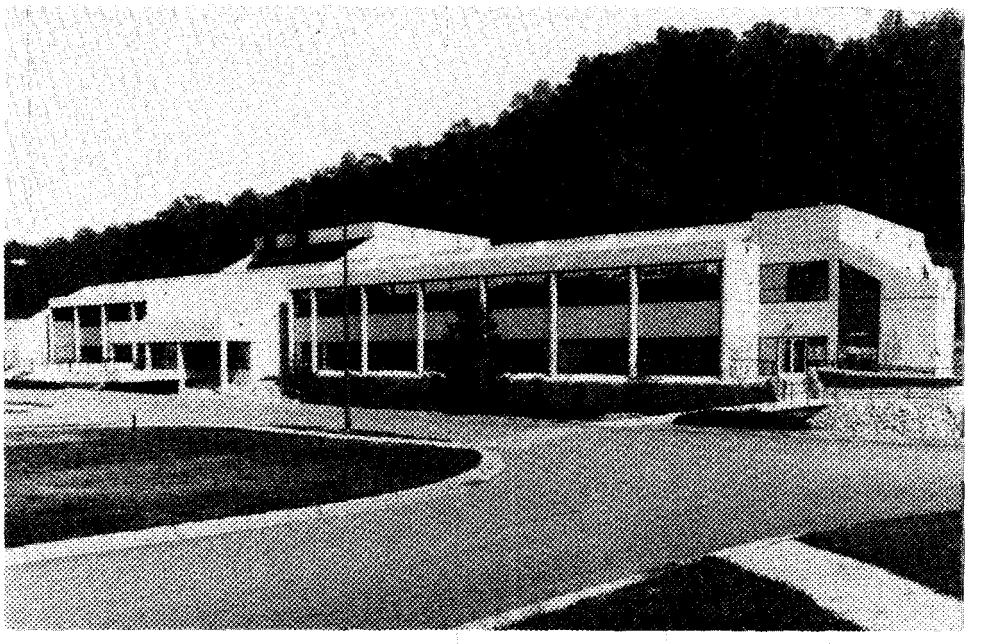


Fig. 2. The High Temperature Materials Laboratory, one of ORNL's user facilities, serves researchers from industries, universities, and other laboratories as a focal point for multidisciplinary research on new ceramics and metal alloys having potential for high-temperature applications.

substantial educational programs. The present educational activities encompass over 30 programs involving precollege, undergraduate, graduate, and postgraduate students and faculty. The potential for our precollege program is particularly significant. If the United States is to regain its leadership in international commerce, we need to influence the nation's best and brightest young people to pursue scientific and technical careers. That is the aim of the Laboratory's Ecological and Physical Sciences Study Center, which attracted 16,000 precollege students last year. The center provides students with the opportunity for hands-on learning in the physical and life sciences.

To a growing extent, the exceptional scientific and technical developments coming from ORNL are being translated into new American products, markets, and jobs. The catalyst for this evolution in the Laboratory's traditional role is an aggressive technology transfer program, one which recognizes the importance of face-to-face interaction between ORNL researchers and their industrial counterparts. This program began in 1985, and as of mid-1990, the Laboratory had in place 45 licensing agreements with American industry. The cumulative product sales associated with these agreements is $30 million and growing rapidly. ORNL has established itself as a leader in technology transfer, and we plan to continue that leadership in the future.

Research and Development Programs

Energy Technologies

The future emphasis of energy R&D at ORNL will be on energy efficiency improvements (both supply and end-use technologies), nonfossil energy supply technologies, and waste R&D.

The Laboratory will continue to conduct a large and diverse R&D program in conservation

and renewable energy. Conservation R&D emphasizes high-temperature materials for transportation and industry, technologies for increasing the efficiency and economical use of energy in buildings and industry, and strategies for improving the efficiency of electricity supply and use. Renewable energy R&D focuses on techniques to reduce the cost and increase the productivity of woody and herbaceous biomass applicable to many regions of the country and in developing nations. Advanced technology for the conversion of biomass to fuels and chemicals will also be pursued.

Energy supply technology development at ORNL will continue to concentrate on fusion and fission. The energy released when light elements are "fused" offers mankind the potential for a limitless source of energy. ORNL plays an important role in the international quest to transform this potential into reality. The Laboratory's long-term strategy for fusion is to strive for scientific and engineering excellence in a broad program emphasizing technology and materials. In particular, work will continue on advances in toroidal confinement, plasma heating, fueling systems, first-wall and blanket materials, and applied plasma physics. A fusion initiative that has been proposed involves upgrading the Advanced Toroidal Facility to full steady-state operation.

ORNL plans to continue a leading role in development of technology for advanced fission reactor concepts and space reactor applications. DOE's current program includes two advanced commercial reactor concepts, the Modular High-Temperature Gas-Cooled Reactor (MHTGR) and the liquid metal reactor. ORNL's current role in DOE's space reactor program includes production of the encapsulation hardware for the radioisotope thermoelectric generators (RTGs) and materials development for the SP-100 program. The RTGs power the current generation of space exploration satellites, and the SP-100 reactor is being designed and developed for future missions requiring higher power levels than RTGs and solar panels can produce.

ORNL also has a lead role in technology development for DOE's New Production Reactors (NPR) Program. Two new reactors are being designed for this program, the heavy water reactor (HWR) and the MHTGR. NPR, DOE's highest priority program, is expected to have new production capacity on-line by the end of this decade.

The commercial and NPR versions of the MHTGR both operate on the steam cycle (SC) whereby hot helium gas from the reactor passes through a steam generator (gas-to-water heat exchanger), producing steam that is used to drive a turbine.

A new initiative is ORNL's collaboration with the Massachusetts Institute of Technology to further develop a concept first proposed for the high-temperature gas-cooled reactor in the 1970s. By eliminating the steam generator and using the hot helium gas, which exits in the core of the MHTGR to drive a gas turbine, a considerable gain in efficiency can be achieved. The direct cycle (DC) MHTGR can have efficiency in the 50% range, compared to about 37% for the SC and 33% for water-cooled reactors operating on the SC. The MHTGR-DC is just one of several advanced applications for gas-cooled reactors now being considered at ORNL.

Another new initiative relates to the Space Exploration Initiative (SEI). During FY 1991, ORNL will contribute to a technology assessment to support nuclear propulsion. ORNL's goal is to be assigned technical responsibility in the areas where the Laboratory is already contributing to DOE's advanced power reactor program and space reactor program. SEI will likely be the next "big science" project for the U.S. scientific community, and nuclear propulsion is just one of several areas in which ORNL can contribute.

The Laboratory is aggressively pursuing initiatives in the waste R&D area. The emphasis is to develop, demonstrate, and test technologies that address environmental restoration or waste management problems throughout Energy Systems. Energy Systems' concerns are so diverse that issues facing them invariably apply to other sites within the DOE complex. To that end, staff works closely with Energy Systems' Environmental Restoration and Central Waste Management divisions to

propose solutions to problems they have identified. The goal is to rapidly solve problems in the most cost-effective manner possible without undue risk to human health.

Fossil energy activities reflect the Laboratory's strong conviction that fossil energy, especially coal, is one of the most important areas for R&D. Fossil energy R&D will focus on materials research and development; environmental, health, and safety (ES&H) activities; bioprocessing of coal to produce liquid or gaseous fuels; combustion research; and modeling activities on the operational requirements for the Strategic Petroleum Reserve. Materials R&D will cover research on ceramic composites, advanced austenitic alloys, iron aluminides, corrosion-resistant alloys, and the mechanisms of erosion and corrosion. Advanced ceramic membranes, ceramic composites, and alloys will be examined for gas separation and filtration applications. Materials technical support and failure analyses will be provided to projects on the Clean Coal Technology Program. Work will be conducted on the chemistry and structure of coal surfaces and interfaces to understand the complex processes occurring in coal during combustion. The ES&H activities will primarily address documentation required by the National Environmental Policy Act for projects on the Clean Coal Technology Program. In addition, technical support will be provided to DOE on issues surrounding global warming, air quality, and solid waste. In the combustion area, characterization and combustion of products from mild gasification processes will be examined.

The Sciences

The Laboratory will maintain vital programs in both the physical and life sciences. The science programs serve two important purposes: they add to the storehouse of fundamental knowledge and they create a strong scientific base in support of the Laboratory's technology programs.

Areas of research in the physical sciences will include materials; computations; robotics and intelligent systems; chemistry and chemical engineering; and atomic, nuclear, and high-energy physics. The goal of the ORNL materials program is to continue as a world leader in high-temperature materials development and solid state physics, including surface research, preparation of new materials, advanced materials processing, and neutron scattering (Fig. 3). Advances in neutron scattering research are heavily dependent on the ANS project. One area of emphasis in computations will continue to be research on parallel processing. In robotics and intelligent systems, research topics will include teleoperations and autonomous systems with man-machine symbiosis as the ultimate goal. Chemistry and chemical engineering research will emphasize separation science and technology, photo and biophoto chemistry, and biochemical engineering research. In physics, the addition of new instruments to the Holifield Heavy Ion Research Facility (HHIRF) would make ORNL the world center for nuclear structure research, at least through the end of the century. The HHIRF, a user facility, provides world-class opportunities for nuclear structure research for investigators from across the nation. It is also an important national facility for promoting graduate and undergraduate education in nuclear physics.

The Life Sciences

Biology and environmental sciences will continue to grow as essential elements of the Laboratory's research programs. In biology, the plan is to build on the core areas of mammalian genetics, radiation carcinogenesis, and protein engineering. In addition, it is planned to expand multidisciplinary research in structural biology and genome mapping. The proposed new Center for Biological Science will provide important new research tools to be used by the ORNL staff and by outside users from universities and industries.

Health and safety research will continue its focus on the measurement and assessment of human health impacts of radiological and chemical substances. Emphasis will be in

- improving the understanding of pollutant interactions at the atomic and molecular levels;

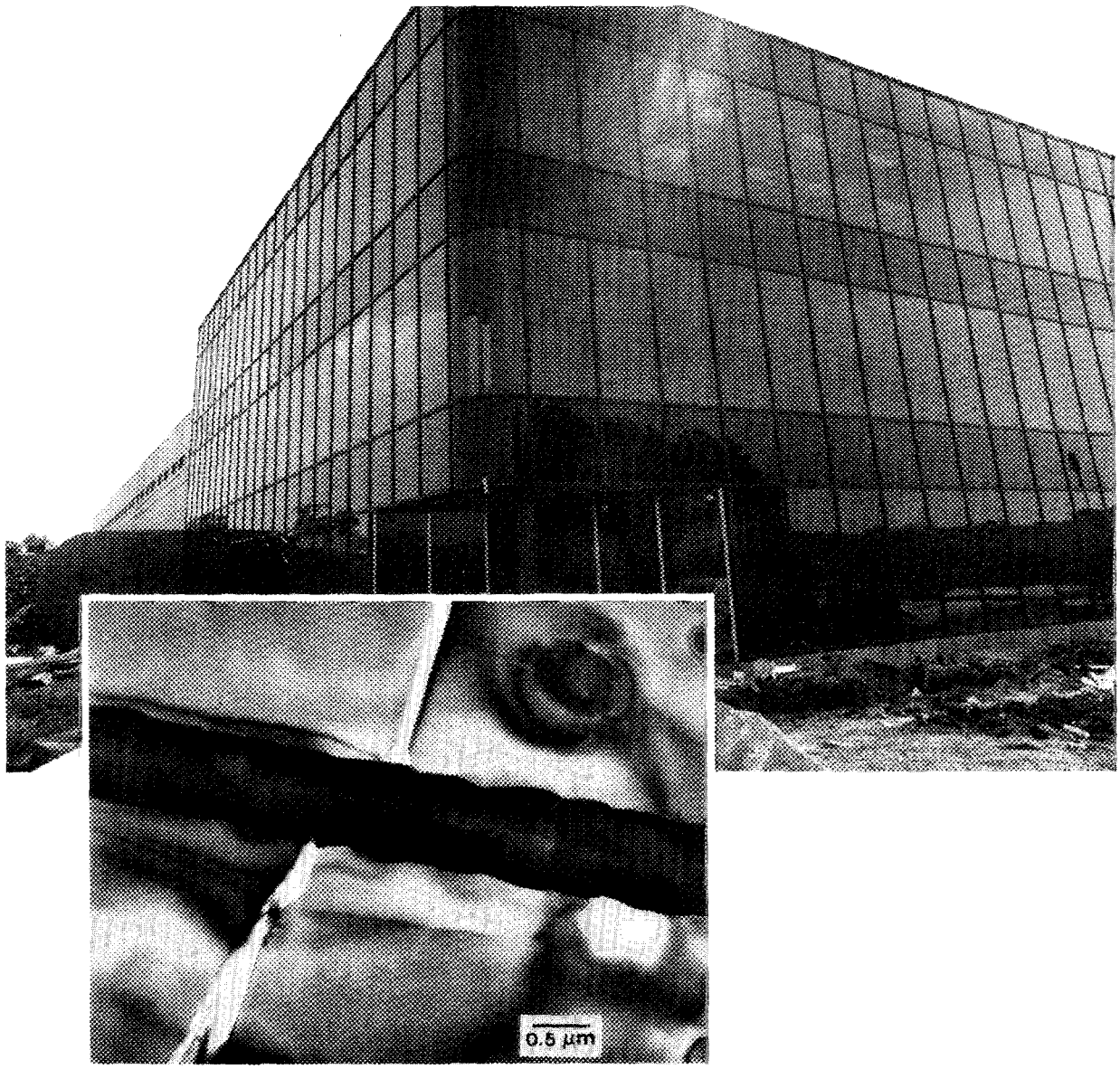


Fig. 3. ORNL is making major contributions in advanced ceramics such as this composite in which ceramic "whiskers" reinforce the matrix, bridging small cracks to prevent their growth. In similar fashion, the Laboratory's materials-development work spans the traditional void between basic research and industrial applications. Our unique range of capabilities has attracted several major firms, including Hertel Cutting Technology (shown here) and Coors Ceramics, to Oak Ridge's "Ceramics Valley."

- applying tunneling microscopy to studies of biosurfaces;
- enhancing studies of the liquid state of matter;
- developing advanced photonics for environmental needs; and
- continuing progress in the development of radiopharmaceutical products for routine clinical applications, advanced information management techniques, and state-of-the-art site characterization methods and instrumentation.

The program goals are to continue to maintain world leadership in radiation dosimetry and to establish a center of excellence in health risk analysis.

In the environmental sciences, the broad goal is to retain the Laboratory's status as one of the world's premier ecological-environmental research centers. The environmental sciences program will cover both energy-related environmental issues and global science. An important objective is to study and understand the interactions of physical and chemical agents with living organisms, including the ultimate consequences on the environment. Global environmental studies will be directed toward gaining the fundamental understandings needed to deal intelligently with the major global-change issues, including global warming (Fig. 4). One of the goals is to provide practical input to decision makers for making technology and policy decisions.

Managerial Implications

Progress in the thematic areas of energy, environment, and competitiveness will require the Laboratory's and DOE's managements to concentrate on four issues. First, the infrastructure

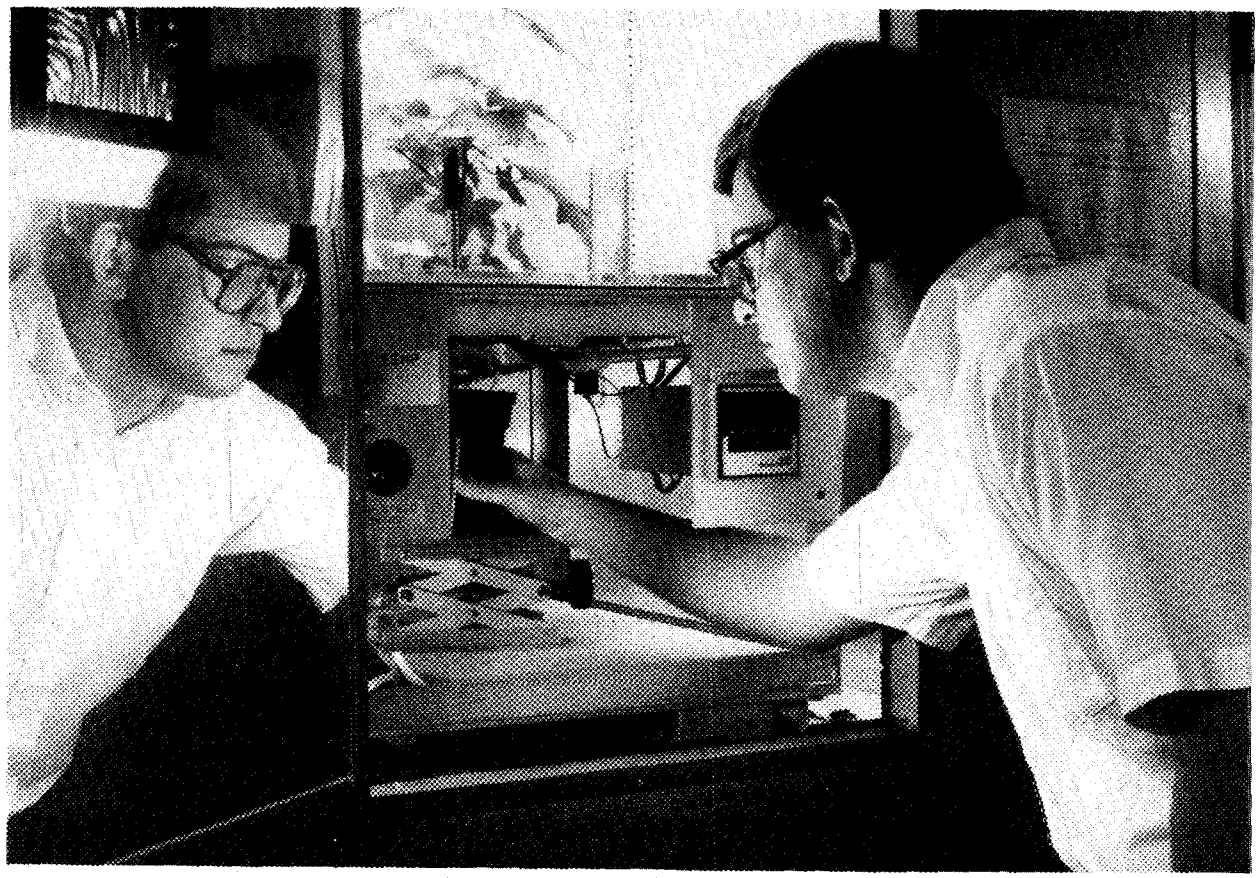


Fig. 4. Paul Hanson, researcher in the Environmental Sciences Division, installs a hardwood seedling in a gas reaction chamber to measure deposition of trace nitrogen gases on foliar surfaces. Results are used to assess the relationship between biogeochemical cycling and global climate change.

of the Laboratory must be rebuilt and expanded. At the same time, ORNL needs to be able to manage its available resources to achieve excellence in operations relative to environment, safety, and health protection while maintaining a suitable environment for performance of world-class R&D. Additionally, we must continue to expand our interactions and collaborations with outside organizations, especially universities and American industries. Finally, and most important, we must enhance our ability to attract, develop, and retain quality staff.

Rebuilding and expanding the infrastructure of ORNL requires management attention to decommissioning several "legacy" facilities, upgrading most existing facilities to meet current safety and environmental standards, replacing some existing buildings, and acquiring new research facilities to serve as national user facilities. As noted previously, the most important of these new user facilities is the ANS.

Although the Laboratory has made significant progress in meeting ES&H needs and requirements, much remains to be done. The challenge is complex, especially given the age of our facilities, increasingly rigorous DOE and other agency regulations, and limited financial resources. ORNL and DOE need to continue to work together to prioritize ES&H needs to be able to address the most critical ones first within available resources. And all this must be accomplished without jeopardizing the Laboratory's current and future R&D viability.

Continued expansion of the Laboratory's interactions and collaborations with outside organizations will require considerable effort to make ORNL more "user friendly." Both the DOE and ORNL managements will need to pay more attention to simplifying general access and user agreements, streamlining approvals for foreign nationals, and providing services for guest researchers.

The *Workforce 2000*[1] report, as well as other demographic studies, predicts a future shortage of the kinds of people the Laboratory needs. This means that management will need to pay much closer attention to remaining competitive in hiring, developing, and retaining a highly competent staff. Attention must, of course, be paid to being competitive in salaries, but benefit packages and opportunities for career development will be even more important. Special attention will need to be paid to the needs of working mothers, single parents, and employees with diverse cultural backgrounds.

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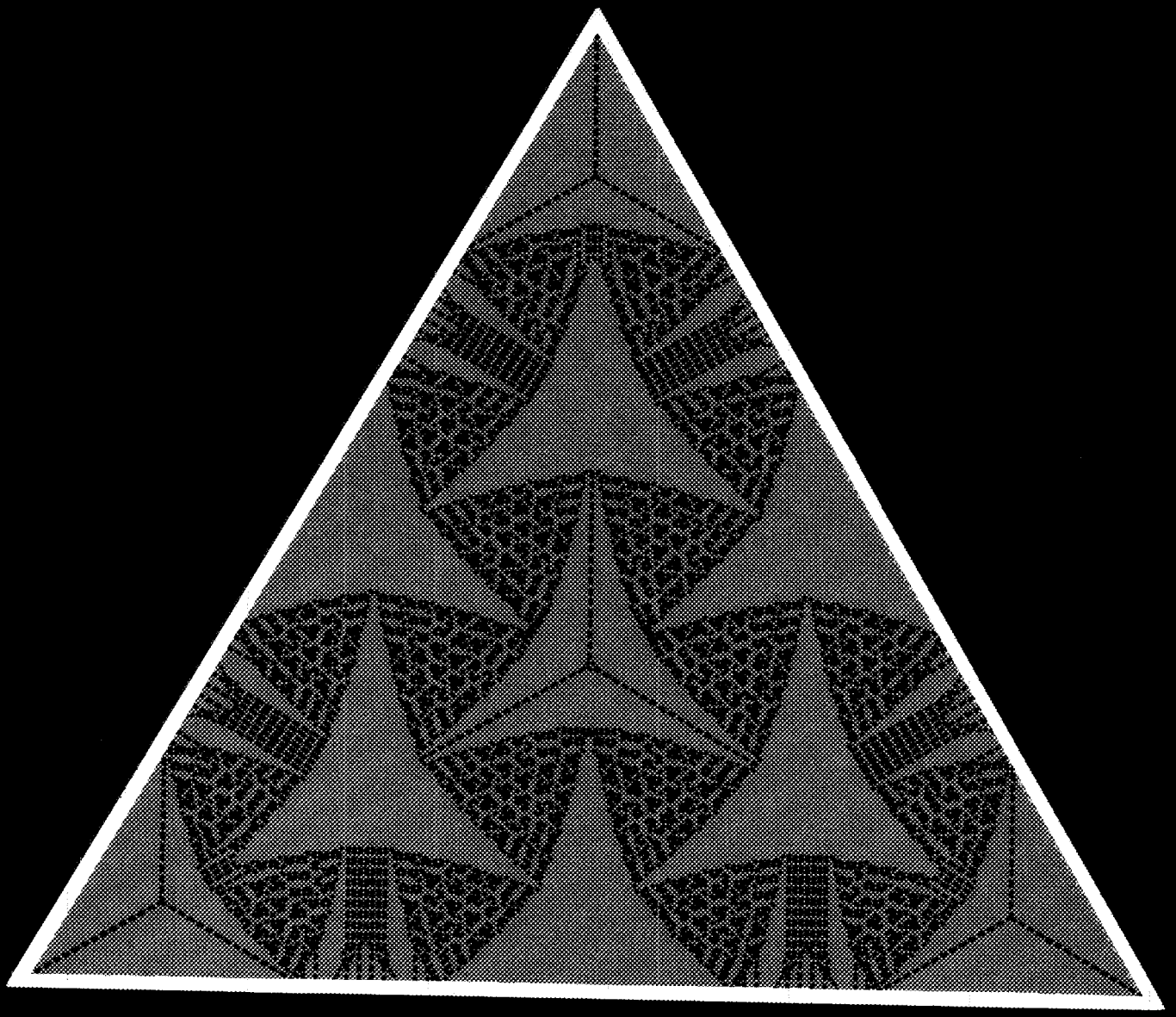
[1]Johnston, William B. and Packer, Arnold E. *Workforce 2000: Work and Workers for the 21st Century,* Indianapolis, Ind., Hudson Institute, June 1987 (U.S. Government Printing Office).

Initiatives



Advanced Neutron Source

The Advanced Neutron Source (ANS) Project will provide an intense, steady-state neutron source to support research programs that broaden the body of knowledge on which today's applied technologies rest and will allow research on new technologies that will be important in the coming decades.

A portion of the mission needs of the ANS is currently provided by the High Flux Isotope Reactor (HFIR) and the High Flux Beam Reactor; however, these existing facilities are 25 years old, and they cannot be modified to meet future neutron research needs effectively. The ANS will be able to replace both of these facilities and greatly enhance the research capabilities in neutron scattering for condensed matter physics, materials science, chemistry, and biology. In addition, the ANS will maintain or improve capabilities for special isotopes production (such as californium), materials irradiation studies, neutron activation analysis, and nuclear physics.

Specific technical objectives for the ANS are established by the National Steering Committee for an Advanced Neutron Source, which comprises more than 30 representatives from Department of Energy laboratories, the National Institute for Standards and Technology, universities, and industries. The Steering Committee provides a forum for the various user communities to identify anticipated needs and to weigh the trade-offs associated with conflicting requirements between the different technology groups.

To achieve the performance criteria, it is necessary to design and construct a small, high-specific-power reactor with a nominal thermal output of ~350 MW. Corrosion of aluminum alloy fuel cladding in ultrahigh flux research reactors such as the ANS may pose special temperature and structural problems associated with the formation of an oxide layer during the lifetime of the core. Earlier research, mostly in support of the HFIR and the Advanced Test Reactor (ATR) designs, has indicated that under extreme heat transfer conditions the exposure of aluminum and many aluminum alloys to water typically leads to the growth of an adherent oxidation product of significant thickness. At the anticipated high-heat flux levels for the ANS core (of order 6 to 11 $MW \cdot m^{-2}$), interposing an oxide film of low-thermal conductivity between the fuel plate and the cooling water may, in certain instances, lead to plate overheating. To ensure that both the fuel and cladding integrity are maintained under the unique conditions imposed by the ANS fuel plates, an experimental facility has been constructed to allow detailed study of this type of corrosion behavior for a wide range of thermal-hydraulic conditions.

The Corrosion Test Loop Facility (Fig. 5) has been in virtually continuous operation since its installation in January 1988. Briefly, the test apparatus is based on a forced-flow water loop fabricated entirely of type 304L stainless steel components, operating at pressures up to 7 MPa. The loop is completed by a specimen of the sample aluminum alloy in the form of a tube enclosing a rectangular flow channel that has the same narrow dimension (1.27 mm) as the gap between ANS fuel plates. The overall channel dimensions allow tests up to coolant velocities of 30 $m \cdot s^{-1}$ at the maximum flow rate (2 $L \cdot s^{-1}$). The specimen is welded to large electrodes, installed into the main section of the loop, and surrounded by electrical and thermal insulation and pressure backing. The heat flux (up to 20 $MW \cdot m^{-2}$) is produced by Joule heating of the specimen using a 30-kA dc-power supply; downstream of the specimen, the heat is removed by a water-cooled heat exchanger. A low-pressure bypass (cleanup) line is used in the same way as in a real reactor to

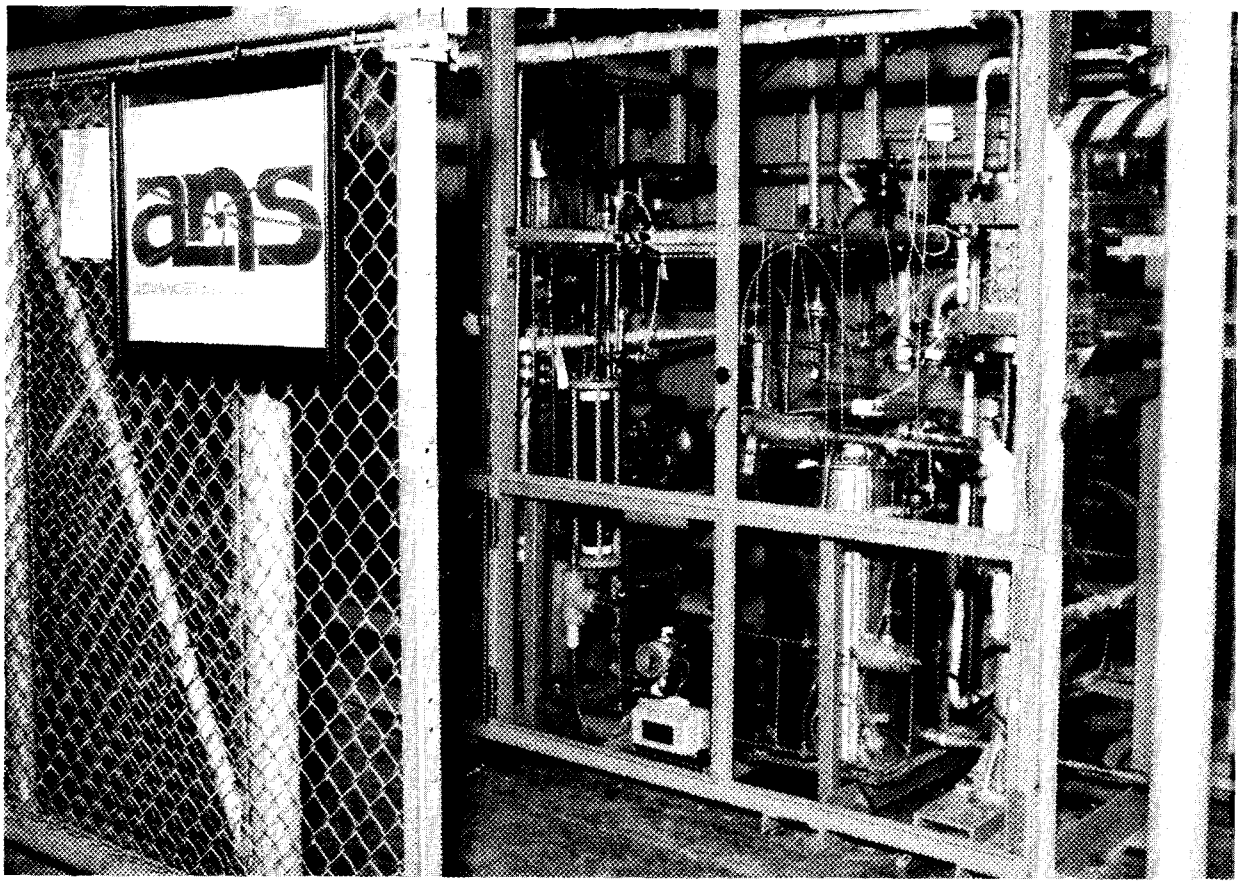


Fig. 5. ANS Corrosion Test Loop Facility.

permit instrumentation and to provide water chemistry control within the loop, principally by deionization followed by pH control using nitric acid addition.

The project schedule indicates that reactor startup would occur late in FY 1999, which approximately coincides with the estimated end-of-useful-life for the existing reactors. The ANS goal is to have an 80% operational availability to support research and isotope production activities, and it will be designed, in accordance with DOE orders, to meet or exceed Nuclear Regulatory Commission (NRC) requirements for comparable licensed facilities. Figure 6 shows some of the safety features of the ANS reactor system.

Preliminary projections for the total project construction-phase cost are in the range of $675 to $850 million (actual year dollars). Detailed budget projections are included in Table 1.

The ANS Project has been supported through the DOE Office of Basic Energy Sciences (DOE-BES). The project recently initiated a conceptual design, with a conceptual design report scheduled for completion in late FY 1992. During the past year, a conceptual design-phase reference core and a reference design for the primary and secondary cooling systems were defined and documented.

Design and construction of a reactor that will meet all of the performance criteria are considered

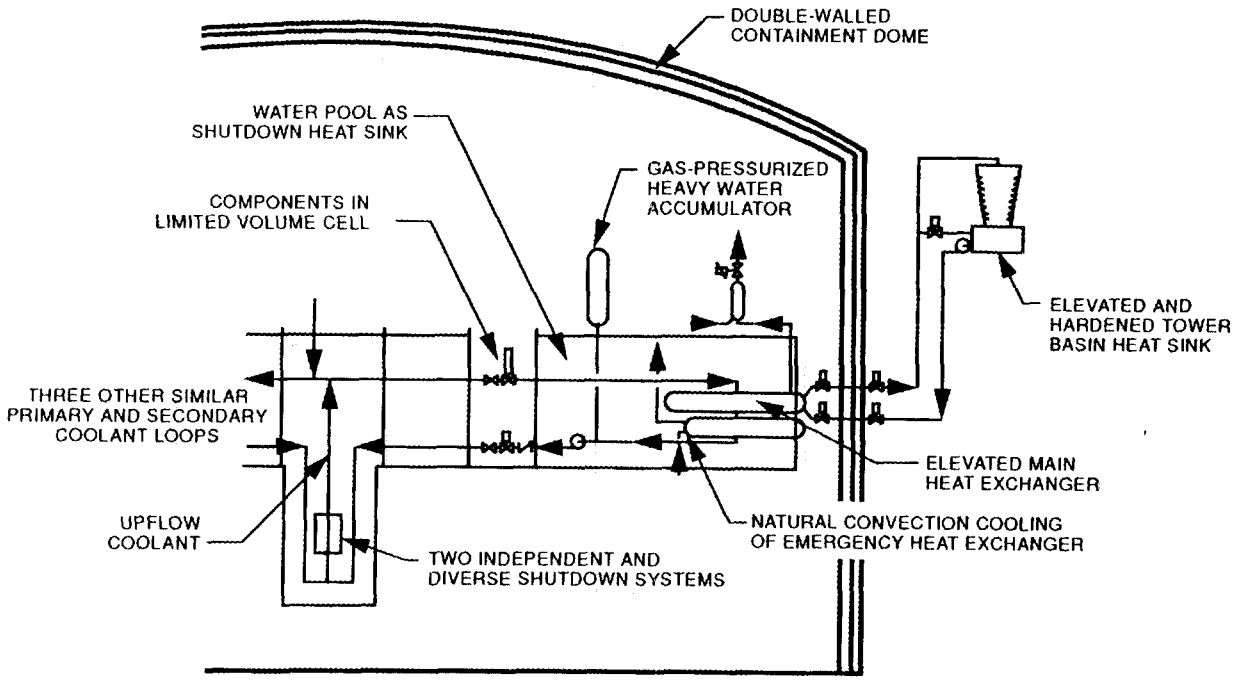


Fig. 6. Some safety features of the Advanced Neutron Source reactor design.

feasible. The need for early documentation of safety analyses, and for preparation of the Environmental Impact Statement prior to a commitment of detailed design, prompts a phased approach to the project. The ANS Project is structured as a 2-year design-only phase (FY 1992–1993), followed by a design completion and construction phase (FY 1994–1999). This provides an FY 1999 goal for reactor startup, with design proceeding at a controlled pace to allow for resolution of the remaining uncertainties. The approach also reduces the risk of future schedule delays and cost growth by providing a firm design basis before construction funds are committed.

Table 1. Budget projections (BA) for the planning period by fiscal year for the Advanced Neutron Source ($ in millions)

	1989	1990	1991	1992	1993	1994	1995	1996
Operating funds	7.4	8.7	12.0	8.6	7.2	7.1	6.5	6.5
Capital equipment	0.4	0.8	0.3	1.4	0.6	2.3	0.6	0.6
Design-only line item				37.7	36.6			
Construction line item		TBD[a]	TBD	TBD	TBD	TBD[a]	TBD	TBD
Total	7.8	9.5	12.3	47.7	44.4	TBD	TBD	TBD

[a]To be determined during conceptual design phase.

Modular High-Temperature Gas-Cooled Reactor Technology Development—Direct Cycle

One of several unique features of the High-Temperature Gas-Cooled Reactor (HTGR) is the ability to produce very high temperature working fluid. Coolant outlet temperatures for other reactors in commercial service [light water reactors (LWRs) and liquid metal reactors (LMRs)] are limited by permissible service conditions for the metallic components in the core and the fuel. Higher coolant outlet temperatures make possible higher thermal efficiencies in electricity production and numerous high-temperature advanced applications beyond electricity production. The all-ceramic core HTGR can produce coolant outlet temperatures in the 750°C range with currently available fuels and materials technology. Improved fuel designs and heat transport system materials selections can raise the temperature to 950°C. Developments such as insulating coatings for metallic components and structural ceramics could push this well above 1000°C. For comparison, current LWR and LMR outlet temperatures are in the ranges of 300 and 500°C respectively.

Development of the HTGR for commercial SC application is nearly complete. The modular design (MHTGR) offers safety and investment protection features not available in any other fission reactor concept. However, economic compromises are required to obtain these attractive features. The MHTGR core has a very low power density compared to LWR and LMR designs (6 w/cc compared to 80 w/cc for LWRs and 300 w/cc for LMRs). The low-power-density, high-heat-capacity MHTGR core can easily dissipate decay heat without requiring active safety systems or operator action. Because there are economies associated with modular construction and elimination of redundant, active safety systems, the overall MHTGR capital cost has been estimated to be 20 to 30% more than coal plants of the same size. Current program emphasis is to identify design changes that can reduce costs to a level that will make the MHTGR economically competitive.

The increased safety available with gas-cooled reactors is attractive to utilities, regulators, and the public. However, both the nuclear industry and the regulatory community agree that currently operating LWRs are sufficiently safe. Neither utilities nor the public is willing to pay more for increased safety margins when the existing product (LWRs) is judged to be adequately safe. Power producers might be willing to pay a premium for increased investment protection, but the large premium currently calculated is judged to be too large. The bottom line is that MHTGR power costs must be reduced to the LWR level before a market will exist.

If the helium outlet temperature can be increased from 700 to 850°C, the MHTGR can be designed to operate in the direct cycle (DC) mode. In this mode, hot helium coolant gas from the core is used to directly drive a turbine instead of being sent to a heat exchanger to produce steam, which is used to drive a turbine. The energy conversion area (ECA) for a steam cycle (SC) MHTGR (MHTGR-SC) (Fig. 7) represents approximately one-half of the estimated capital cost. Simplification of the ECA by replacing the SC components (steam generator, feedwater pumps, and feedwater heaters) with a DC balance of plant is expected to halve the cost of the ECA, reducing the total plant cost by about 25%. The capital cost reduction coupled with the higher thermal efficiency (50% for the DC and 37% for the SC) should make the MHTGR-DC cost competitive with LWRs and with fossil plants.

At this time, DOE's MHTGR program is focused on the MHTGR-SC rather than the MHTGR-DC technology development (Table 2). However, DOE does have an interest in reducing capital costs for the MHTGR-SC design and has an active program in place. ORNL's initiative includes preconceptual design analyses to provide

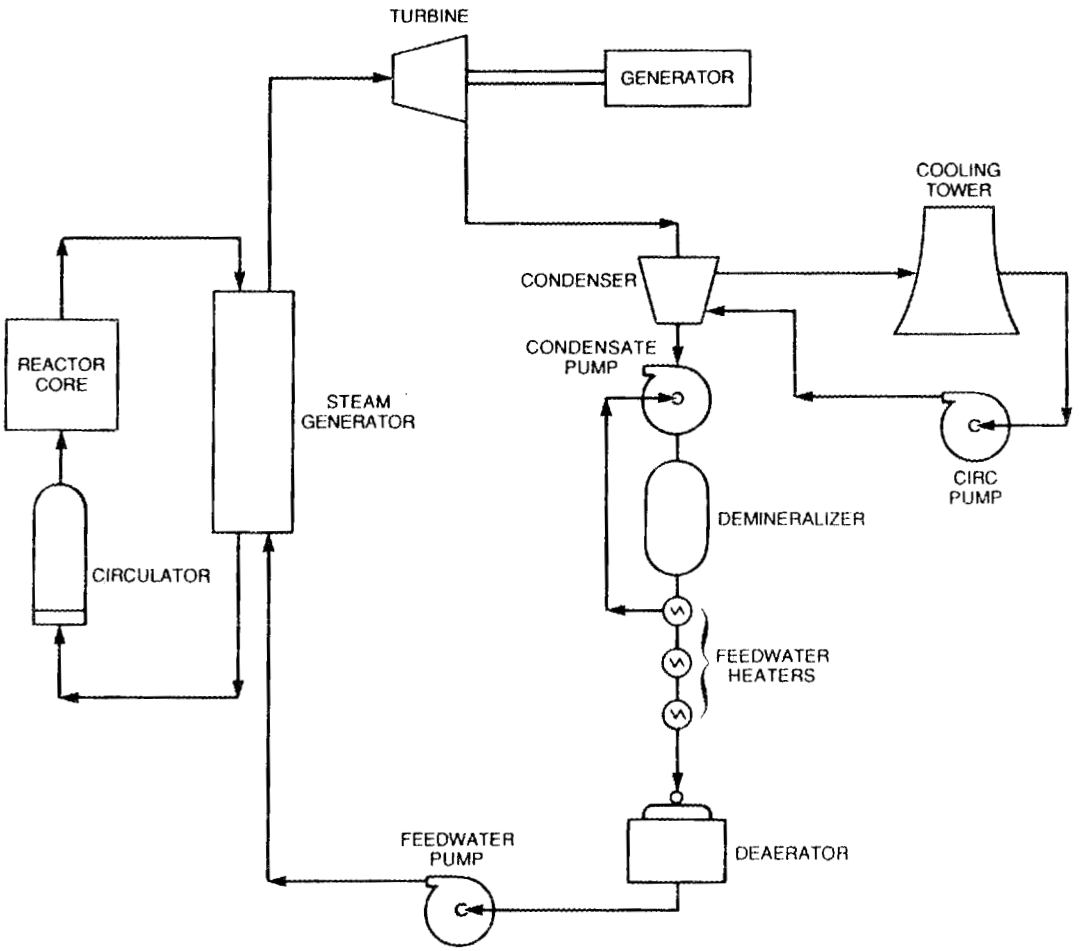


Fig. 7. Basic High-Temperature Gas-Cooled Reactor steam cycle flow diagram.

Table 2. Budget projections (BA) by fiscal year for the Modular High-Temperature Gas-Cooled Reactor—direct cycle initiative ($ in millions)

1990	1991	1992	1993	1994	1995	1996
0	0	0.5	1.0	3.0	5.0	7.0

cost estimates for both the MHTGR-DC plant and the additional technology necessary (beyond what is being done for the MHTGR-SC) to support the MHTGR-DC design. The cost comparison and technical feasibility of the MHTGR-DC is expected to generate substantial interest for the MHTGR-DC in the industry, including nuclear steam supply system suppliers, utilities, architect–engineer firms, and component manufacturers.

Center for Excellence in Research Reactors

A serious national dilemma exists because of the continued decline in the number of research reactors in this country and the growing need for such facilities in the future.

Traditional uses for research reactors are expected to continue (e.g., neutron radiography; activation analysis; medical isotope production; biomedical irradiations; materials studies; and commercial product preparations). In addition, much more exciting work is yet to be done, including, for example, research in advanced ceramics and high-temperature superconductors.

Furthermore, the uses of neutrons in experimental research could increase significantly if an effort is made to identify potential users and to inform them of the current availability of the reactor facilities. The decline of interest in nuclear power reactor technology during the 1970s, the permanent closure of many research reactors during the 1970s and 1980s, the shut down of ORNL and other DOE reactors for exhaustive reviews in the late 1980s, and the announced shutdown of others to occur in the early 1990s has left researchers seeking facilities that can provide the proper combination of neutron flux, irradiation sample space, temperatures, and other parameters for their experiments. Some of the DOE reactors that were shut down have since been restarted, some are still shut down, and others may not be allowed to continue operations in the present environment of increased standards and constrained funding. During the late 1980s, ORNL had numerous requests, which had to be declined, from researchers around the world inquiring about using our reactors. Because the HFIR and the Tower Shielding Reactor (TSR-II) have been returned to service, some of these needs may now be met. Additionally, in the future, it may be possible to restart the Health Physics Research Reactor (HPRR) based on cost-recovery operations if sufficient resources to support restart costs can be identified. In carrying out activities to restart the research reactors, ORNL made a major commitment to pursue excellence in all aspects of research reactor operations and associated science, both now and in the future. As such, it is considered most appropriate to tie this commitment with the need to promote future utilization of research reactors. The Center for Excellence in Research Reactors (CERR), proposed specifically for DOE's Office of Energy Research (DOE-ER) and DOE-NE consideration, would provide a mechanism to match users with research reactors not only at ORNL but throughout the country; this would promote excellence in all aspects of reactor operations.

Knowledge shared by CERR about specific capabilities of and access to the country's research reactors would stimulate interest in research that requires unique reactor facilities. A "feeder system" of multiple research programs is important to the HFIR, TSR-II, and ANS as well as other DOE research reactors. By having a "fleet" of reactors easily available and operated in the pursuit of excellence, research programs will be stimulated, and the overall effectiveness of the country's research reactors will be improved.

The serious dilemma of declining numbers of operating U.S. research reactors, combined with projections of increasing needs for these facilities, has not escaped the notice of the nation's research community. A 1988 study of university research reactors done by the National Research Council (*University Research Reactors in the United States: Their Role and Value*) pointed out that this problem must be resolved soon if the United States is to maintain technological leadership in many important scientific areas. The four principal recommendations concerned the following:

- development of university and national laboratory centers of excellence in specific areas of the neutron sciences and reactor technology for world-class research and education;
- anticipation that as some university reactors are upgraded and a users' network is created, others are likely to close;

- mechanisms to ensure that such closures do not damage the national interest related to research and educational capabilities in the nuclear sciences and engineering; and
- development and support of a reactor network to facilitate improved use and productivity of U.S. research reactors involving researchers from national laboratories and universities with and without on-campus reactors.

There is also evidence that the dilemma with research reactors is being recognized by the U.S. Congress. The FY 1990 Appropriations Committee reports (accompanying H.R. 2696, Energy and Water Development Appropriations Bill, 1990) described the Committee's concern that no unified strategy exists for integrating and supporting university-based research reactors. The House and Senate committees directed DOE to complete a utilization plan for all research reactors and to determine the feasibility of establishing a national advisory committee to advise DOE on the plan. DOE submitted the report to Congress in July 1990, and the specific recommendations are being reviewed.

One of the problems leading to the present dilemma has been the lack of any institution having the purpose or the resources to identify the existing and projected needs of the user community for research reactor facilities and to develop an integrated strategy that would ensure these needs could be met. Many outside researchers do not have an official source of information, and because of the Laboratory's reputation in reactor-based research, they often call ORNL personnel for help in locating a reactor that is appropriate for their experiments. This situation clearly reflects the findings of the previously cited study by the National Research Council.

As a positive step toward reestablishing U.S. leadership in nuclear technology, the organization of a CERR within DOE is proposed. Specific objectives of this program would be to

- determine existing and projected user needs for research reactor facilities;
- collect, analyze, evaluate, and maintain data on existing research reactor facilities relative to current and projected user needs;
- develop a unified strategy for establishing and maintaining a viable network of research reactor facilities;
- establish and maintain a regional center at ORNL to meet possible needs of the user community and to stimulate new and expanded use of research reactors (similar centers may be established in other regions); and
- establish and maintain a regional center at ORNL to promote excellence in all aspects of ORNL research reactor operations.

Such a comprehensive national research reactor program should encompass all U.S. research reactors at both universities and the national laboratories and should involve individuals from throughout the entire nuclear technology community, including representatives of industrial users.

The proposed program plan would require significant initial effort, with the aim of accomplishing the first three objectives within the program's first year. Beginning in the second year, two regional centers would be established as institutional entities whose purpose would be to increase communications and interactions with the user community. These centers would provide ongoing coordination and integration services between the ORNL reactor operators and prospective users. The ORNL plan would have no provision for any operational responsibilities for the reactors; the full responsibility for operating each reactor in compliance with respective orders or regulations must remain with the owners/operators. The ORNL center would stimulate increased usage of the reactors and help make the facilities more user friendly.

With ORNL's commitment to continued excellence in the operation of the HFIR and the TSR-II, the restart of other ORNL research reactors, and the ANS Project, we are heavily committed to the research reactor mission. Therefore, it is appropriate for us to be a leader for the national effort. The ORNL CERR would serve as a focus for user needs for the HFIR, the

ANS, and all U.S. research reactors willing to participate in the collaboration. We believe this approach will best serve the users and will maximize the services from both existing and planned reactors.

Budget projections for the ORNL CERR are provided in Table 3; funding for this initiative has not been included in the Appendix.

Table 3. Budget projections by fiscal year for ORNL's Center for Excellence in Research Reactors ($ in thousands)

1992	1993	1994	1995	1996
315	330	345	360	380

Energy Technologies for Developing Nations (Including Eastern Europe)

The energy choices made by developing nations (including those of Eastern Europe) will have growing environmental and economic ramifications for the United States. Clearly, as the economic gap between developing and industrialized nations narrows, an increasing share of the world's primary energy use will go to meet the needs of developing countries (Fig. 8). This means at least three things to the United States: (1) Resulting energy use by developing nations, including fossil fuel consumption, is likely to contribute significantly to the global build up of greenhouse and ozone depleting gases in the atmosphere. (2) CO_2 emissions by developing nations (including China) may exceed those by industrialized nations in the first decade of the next century. Energy use by developing nations is also likely to contribute to rising pressures on world oil markets. (3) Developing nations will be an expanding market for energy technologies during a time when the United States is trying to improve its competitiveness in the world economy.

Energy technology research and development (R&D) can be an important part of the U.S. response to all three of these challenges. In particular, more energy efficient technologies that are economical and much better nonfossil sources will be needed to moderate environmental and oil market pressures. These technologies should be engineered to meet the particular circumstances of each developing country so that adoption rates can be maximized and the U.S. share of energy technology markets improved.

DOE and other federal agencies have already begun to explore these opportunities. An interagency Committee on Renewable Energy Commerce and Trade (CORECT), chaired by a DOE official, is now working to facilitate worldwide use of U.S. renewable energy technologies.

Since 1982, ORNL has been involved in energy technology and policy assessments in developing countries. These assessments have been supported largely by the U.S. Agency for International Development (AID), but increasing support has come from DOE as well. This experience has extended to 21 countries in Asia, Africa, Latin America, and the Near East, and it has embraced fossil technologies, biomass and other renewable resources, and energy efficiency improvements. As a consequence, ORNL represents a unique combination of broad-based developing country experience; broad-based energy

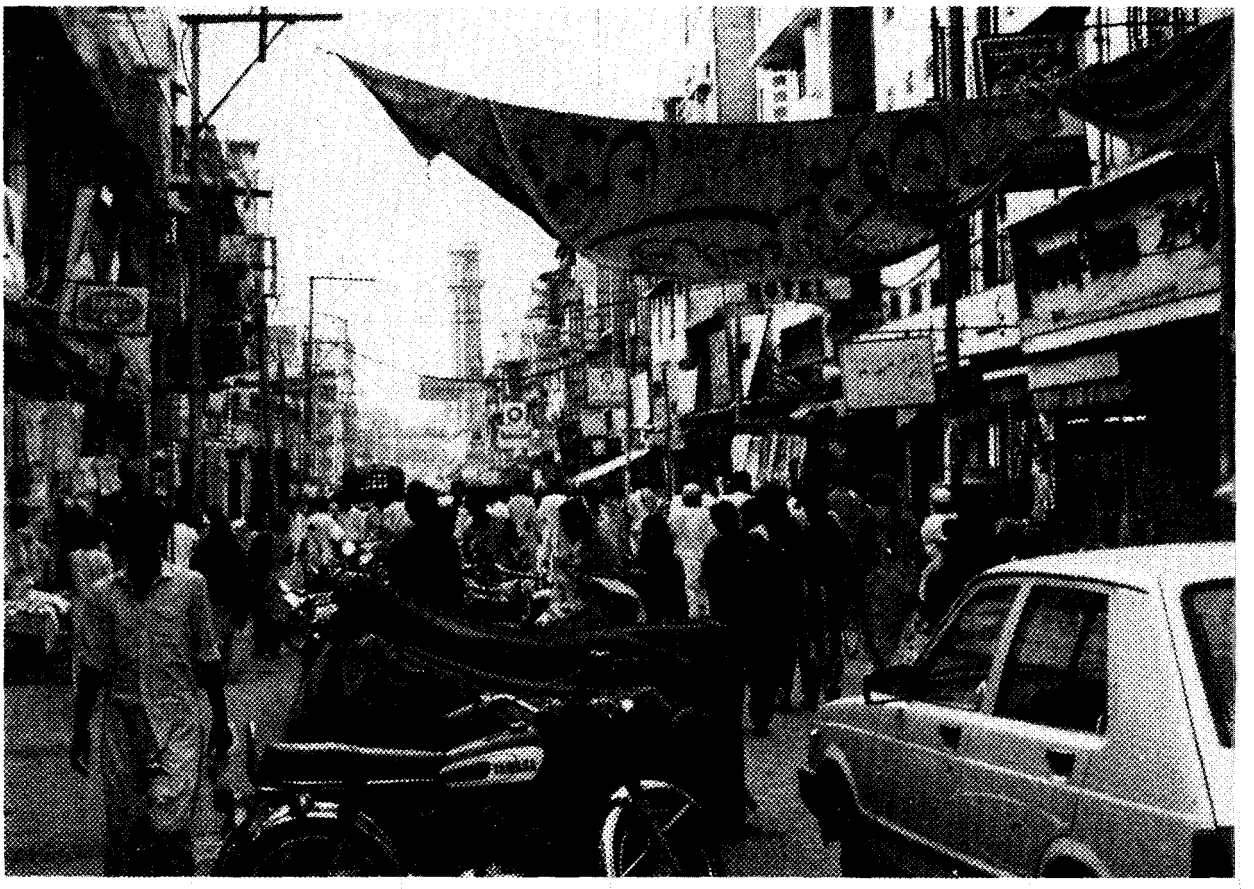


Fig. 8. Rising aspirations and population growth in developing countries such as Pakistan (shown here) add up to growing needs for energy services.

technology R&D expertise and facilities; and informed perspectives on such issues as global climate change, technology transfer, and public-private sector collaboration.

With this background, ORNL's role in what is emerging as a major national initiative will be focused on technology R&D; that is, ways to meet the energy needs for economic growth in developing countries while reducing stress on the global environment and world oil market—and improving the U.S. trade balance—through technology development, improvement, and adaptation.

The ORNL initiative consists of four major activities:

- **Nation- and region-specific R&D agendas**
  In consultation with DOE, ORNL will select a limited number of key nations or regions and, in close collaboration with sister R&D institutions in those areas, will assess needs for energy technology improvements or adaptations to meet their needs. Nations or regions will be selected on the basis of their importance to global warming (e.g., U.S.S.R., China, India, and Brazil); their importance as potential markets for U.S. energy technologies (e.g., Eastern Europe and Southeast Asia); and their importance in meeting development needs (e.g., the Sahel) or U.S. policy objectives (e.g., Eastern Europe and Central America). Based on the

assessments, R&D agendas will be developed and pursued in cooperation with the U.S. private sector and indigenous counterparts. This step will be followed by efforts to encourage the demonstration and use of improved technologies and efforts to transfer the new options to other countries or areas.

- **Selected technology-specific R&D agendas**
  In some cases, ORNL is prepared to combine its developing country experience with DOE program priorities to identify energy technology R&D directions that are likely to meet the needs of a number of developing areas. Some candidate technologies include biomass production and conversion; heating, ventilation, and air conditioning (HVAC) equipment for buildings; technologies for electricity distribution; and power electronics. In such cases, R&D initiatives at ORNL will serve as catalysts for DOE programs and as sources of ideas for the U.S. private sector. For example, two promising opportunities are biomass plantations in China and gas-fired, ground-coupled heat pumps in the U.S.S.R. As external financial support grows, the Laboratory will involve the private sector as a full partner in the R&D process, much like ORNL has done in buildings energy conservation R&D.
- **One-stop shopping centers**
  ORNL can identify opportunities to facilitate the transfer of technologies that have benefited from DOE R&D support. We propose the creation of "one-stop shopping" centers where data, supply network, and expertise resources are coordinated to introduce developing nation customers to private suppliers. For example, in support of this new direction, we propose that DOE expand the scope of CORECT to establish a Center for Global Efficiency, through which many forms of assistance can be provided to developing country energy institutions and end users, including electric power utilities, large industrial energy consumers, trade organizations, energy R&D institutions, and energy equipment and service suppliers. The Center will provide a mechanism through which technical assistance from a broad spectrum of private and public service institutions can be accessed to develop energy efficiency programs. In addition, the Center will also provide technical assistance for specific projects or project development; identify and define collaborative technology research and development efforts; and provide support and training needed to form institutional mechanisms for reasonable operation and success of the integrated utility planning process and resulting technology implementation.
- **Comprehensive energy information system**
  ORNL will explore possible opportunities to create a comprehensive information system to collect and disseminate information about energy technologies, energy assistance activities in the developing countries, and options and purveyors of assistance for the developing countries. The lack of such an information system is a major gap in the current programs of assistance. ORNL's extensive experience with technical information centers should be a major asset as organizations work together to meet this need.

We anticipate sponsorship of the ORNL initiative from the following organizations:

- AID—Related support from AID's Office of Energy and from various missions and regional offices should continue.
- EPA—EPA is pursuing opportunities to assist developing countries with environmental centers. These centers are likely to include energy efficiency initiatives.
- DOE—The background paper for the National Energy Strategy, "Energy Technology for Developing Countries," suggests a major DOE role in energy technology R&D for developing countries. If a program is established to meet this need, it would become a significant sponsor of ORNL's efforts. Principal support is likely to come first from DOE's Office of Conservation and Renewable Energy, but, in time, support might also come from Nuclear Energy, Fossil Energy, and International Affairs. It may be that, if a cross-cutting organization is established in DOE for coordinating global climate response

efforts, this organization could be a source of support as well.

A full national program for energy technology R&D for developing nations might require from $100 to $200 million per year. Table 4 indicates the budget proposed for the ORNL initiative in this subject area. About $1 million of the total in each year, 1990–1996, has been included in the projections for Program EF in the Appendix.

workings of environments in air, on land, and in water;

- developing capabilities to anticipate the long-term, large-scale effects that human actions have on the biosphere; and
- identifying appropriate options for technological and societal responses.

Like the U.S. Global Research Program, the crosscutting national initiative to which the ORNL

Table 4. Combined DOE and WFO operations budget projections by fiscal year for Energy Technologies for Developing Nations[a] ($ in millions)

	1989	1990	1991	1992	1993	1994	1995	1996
Non-DOE (AID)	0.4	0.5	0.8	1.0	1.0	1.0	1.0	1.0
DOE	0.1	0.5	1.2	3.0	7.0	8.0	9.0	9.0
Total	0.5	1.0	2.0	4.0	8.0	9.0	10.0	10.0

[a]Note that these figures are a subset of total financial support for ORNL work in developing countries and, in the case of AID, are less than the total resources projected from that agency in the near future.

Global Environmental Studies

Many of the decisions that will determine our direction in the next millennium hinge on issues that are complex, interwoven, and global in scale: greenhouse gases, climate change, ozone breakdown, deforestation and desertification, resource depletion, and the spread of pollution. These and other global environmental issues must now be explored far more seriously—far more comprehensively—than ever before.

ORNL's Center for Global Environmental Studies, established in 1989, provides a unique, interdisciplinary base for such explorations. The Center has three main goals:

- improving the understanding of the global-scale

Center corresponds, the Center for Global Environmental Studies takes a new view of the kinds of research needed in this formidable but exciting field. The Center's work is based on the unique capabilities of ORNL that set it apart from traditional institutional approaches to large-scale research and analyses.

- The scope of the processes and problems we are exploring is far greater—both in scale and in time—than traditional research projects are equipped to deal with. Problems such as ozone depletion, the greenhouse effect, and global change are no respecters of national borders: they affect the entire planetary commons. Our understandings and responses, therefore, must be equally broad. Similarly, processes such as climate change and dwindling biodiversity may become clearly evident only when viewed over decades or even centuries. We must, therefore,

envision and develop programs that can serve as foundations on which to build for many years.

- Collaboration—both among traditionally competitive institutions and across disciplinary boundary lines—is absolutely essential for any meaningful understandings to emerge. The globe's environment responds to the interactions of many different systems, factors, and processes: air circulation, ocean currents, land-use changes, economic incentives for development (or its converse), the migrations of smokestack industries, national energy practices and policies, and even political turmoil. Narrow, discipline-bound approaches can give us only detailed analyses of individual aspects of the biosphere, for example, individual trees. But what we need now is an overarching view of the global environmental forest.
- Policy—economically and politically practical policy—must be one of the prime drivers of global environmental research. We must consider not only what is happening in (and to) the biosphere; not merely what should, ideally, be done about it; but also what can be done, given the economic, technological, and political constraints within which actions must be taken.

These, then are the principles that guide the Center's organization and work: a large-scale, long-term view; a commitment to collaboration, both among institutions and among disciplines; and a continual eye to realistic policy.

Areas of Focus

In keeping with the Center's large-scale view, the central and unifying framework for our work is global systems analysis: developing increasingly sophisticated models that reflect the dynamic interactions of numerous subsystems—global vegetation; human cultures and behaviors; and Earth systems such as atmospheric chemistry, ocean composition and circulation, and the links between air, land, and sea. Our long-term goal is to develop models that reflect the interplay of demographics, land-use patterns, economics, ecological relationships, and other factors that influence the globe's environment.

Complementing our central focus on global systems are four areas of more specific concentration:

- Measurement science and instrumentation: better monitoring of the state of the environment and its changes. ORNL has a long history of excellence in instrumentation in high-energy physics, health physics, pollution monitoring, nuclear reactor technology, and nuclear and chemical waste. We are now directing this expertise toward instrumentation for atmospheric, terrestrial, and aquatic research. Areas of strength that can immediately benefit the Center include laser-based instrumentation, which we expect to play an increasingly vital role in global-change research; mass spectrometry and isotopic analysis; remote sensing and fiber optics, another key technology for climate studies; and automation, miniaturization, and portability. Logical applications of this expertise include laser-based devices to measure trace gases, temperature, and pressure; low-cost, air-droppable packages for reading atmospheric or ocean conditions; and instruments for studying cloud formation and properties in support of the U.S. Atmospheric Radiation Measurement (ARM) Program.
- Data systems: the key to making sense of the global environment, now and for decades to come. The amount of data collected in the course of global environmental research is already staggering, and it will grow explosively as newer, more sophisticated instruments and monitoring projects emerge. For example, in a few years NASA's Earth Observing System will begin transmitting enough data to fill all the books in the Library of Congress—every three weeks. In addition to handling massive quantities of data, information systems must present the data in a user-friendly form, one that will also ensure the usability of information over decades because the import of some data may not become clear for many years.
- Large-scale environmental studies: projects that examine the environment from a longer

perspective than traditional ecological research. Global-scale studies cannot be based on mere extrapolations of traditional detailed studies; many of the subtle ecological processes on which traditional research thrives are less meaningful for these purposes than aggregate processes that are invisible at close range. The ORNL Center is developing tools and techniques for understanding how to scale up research to the global scale that is now needed.

- Policy, energy, and human-systems analysis: the recognition that humankind is inextricably linked with the physical systems of the Earth. In the past two centuries, our species has emerged as a primary—perhaps the primary—agent of global environmental change. Therefore, questions of human activity and policy, including the effects of technology, energy conversion, land use, population growth, and political and cultural patterns, must play a key role in global environmental studies. The Center for Global Environmental Studies is bringing together anthropologists, economists, political scientists, sociologists, planners, geographers, climatologists, and ecologists to examine the decision processes involved in global management of risks and resources. Building on extensive work already under way at ORNL and elsewhere, we are developing the theoretical underpinnings of a practical approach to the problems of decision-making involving many players and complex technical issues. Ultimately, this approach will produce a blend of theory and practice that erases the line which for so long has separated the "thinkers" from the "doers."

Key Projects and Goals

A brief sampling of current and planned work by the Center for Global Environmental Studies will help convey the breadth of its research and vision.

Current Research

Development of Integrated Land-Use Models Our studies of tropical deforestation in Brazil, sub-Saharan Africa, and Southeast Asia are contributing to the development of a model that integrates the socioeconomic and biophysical aspects of land-use change. For example, because most of the Brazilian deforestation results from road-building and agricultural clearing, the problem—and its solution—involves nearly every element in the global-change picture: land-use, politics, environmental systems, socioeconomic activity, etc. For this reason, our work involves close interdisciplinary collaboration between experts in geography, ecology, transportation, economics, and other fields.

Refined Modeling of the Global Carbon Cycle Carbon dioxide is the greatest single contributor to the greenhouse effect; therefore, a clearer picture of the sources, sinks, and fluxes of carbon throughout the globe is essential in facing the greenhouse effect and the climate changes it may bring. ORNL's Global Carbon Cycle Modeling Group has developed and has access to many carbon-cycle models. After exercising these existing models rigorously, we are now beginning to develop new models that reflect various "feedbacks" within the carbon cycle and are bringing a unifying theme to the development of fully integrated carbon-cycle models.

Analysis of Options for Implementing Greenhouse-Gas Policy Governments can choose from a variety of approaches to reducing greenhouse gases: regulation; fiscal incentives; information programs; research, development, and demonstration; and others. We have identified more than 160 applications of those approaches for the U.S. private sector. Currently we are examining implementation issues—those that may affect negotiations of implementation protocols at any global climate convention dealing with greenhouse gases.

Information Analysis Centers One goal of this initiative is to create massive data bases on worldwide climate. These data bases would allow us to determine whether global warming has actually occurred. We anticipate the need for

additional information analysis centers for ARM project measurements, biomass data, and human-systems data. Another goal is the development of visualization systems for data-intensive studies. ORNL's Carbon Dioxide Information Analysis Center (CDIAC) is a powerful data-management center with proven expertise in global environmental studies; it represents a valuable "head start" in our new Center's data-systems initiative. We are also collaborating in an initiative to establish a Center for Human Dimensions and Global Change Data.

Computer Hardware, Advanced Mathematics, and Model Physics Initiative (CHAMMP) Atmospheric-circulation models pose some of the most complex, computer-intensive problems in scientific research today. ORNL computer scientists and mathematicians are harnessing one of the world's fastest parallel computers for this challenge—ORNL's 128-processor Intel iSPC/860. Later, we plan to add a terrestrial-systems model to the adapted atmospheric model to give a broader and more comprehensive view of our Earth system.

International Development and Global Environment The impacts of both climate change and climate-change policies will fall heavily on developing countries. Our work in this area includes identifying vulnerable regions; determining the effects of existing aid programs on global environmental change; analyzing the impacts of change on current development plans; and finding new opportunities to enhance development and, at the same time, pursue environmental goals. Energy efficiency, institution-building, and technology transfer for developing countries are high priorities for this ORNL activity.

Planned Research

Improved Radiation-Measurement Instruments for the ARM Program Drawing on ORNL's proven expertise, we propose to develop advanced new instrumentation that will provide better data on global radiation and heat fluxes—data that will allow development of more accurate atmospheric models.

Infrared Spectrographic Instrumentation In a collaborative effort with researchers in Canada and the Soviet Union, we will develop an infrared laser-based instrument that can scan the air above a forest and measure trace-gas concentrations and other important phenomena that can help illuminate the interactions of forest and atmosphere.

Policy-Driven Impact Analysis We are in the first stages of developing an integrated approach to analyzing impacts of global environmental change. Current approaches are generally restricted to projecting overnight changes in resources (such as surface water on coastlines) onto current socioeconomic and geographical conditions. The results of such projections are of very limited use to policymakers. Our alternative approach will be an interdisciplinary analysis, one whose starting point will be the real-world problems policymakers face in a given region and time; the analysis will allow for technological and demographic changes and will indicate how significantly climate-change impacts would affect decisions. Our ultimate aim is to devise PC-based decision-support systems for federal, state, and local decision makers.

A Global Vegetation Model Building on our current study of the global carbon cycle, we plan to extend the vegetation model to encompass the entire globe. The expanded effort (estimated to take 10 to 20 years) will represent a major new contribution to global modeling.

Development of Improved Data-Storage Techniques As the ARM program and other data-intensive programs mature, new ways of archiving and accessing information will be needed—ways that preserve the usefulness of prior data while also anticipating even greater future data-handling needs. Our strength in information analysis and management, together with ORNL's

growing expertise in scientific computing, gives us a solid basis for developing better data-storage techniques and systems.

A Comprehensive Global Analysis of Water Resources Despite the current attention to CO_2 and climate change, long-term limits on water resources may prove to be the world's "Achilles heel." Using the techniques and tools we are currently developing, we plan to undertake a major new initiative in water resources.

Summary

The range and depth of ORNL's scientific expertise uniquely qualify the Laboratory to take up the challenges of the Global Change Program. By establishing the Center for Global Environmental Studies, ORNL is drawing on its proven expertise and worldwide scientific connections, while also laying the foundation for expanded, focused research into the problems of global change.

The Center for Global Environmental Studies is dedicated to an Earth system-centered, interdisciplinary approach to scientific research. It views human interaction with the environment—through population distribution, land use, technology, energy conversion, and other processes—as one of the driving forces of global environmental change. The Center stands in a unique position to serve the needs of federal agencies and international efforts and to make a significant contribution to our understanding of the delicately balanced biosphere we call home. Budget projections are given in Table 5.

Life Sciences Complex

The development of the ORNL Life Sciences Complex has been a vision of the Laboratory for many years. The expansion of the west end area of ORNL is of extreme importance to accommodate the growing programs within the life sciences and will support DOE's increasing emphasis on environmental, safety, and health activities. The Life Sciences Complex will provide new, high-tech laboratories for expanding R&D needs of the divisions and will offer modern facilities in place of old buildings that are often crowded, inefficient, and in need of repair. Construction will consist of three line items (the Center for Biological Sciences, the Advanced Photonics Laboratory, and the Earth Systems Facility) and general plant project (GPP) upgrades (Fig. 9). Our programmatic emphasis will be on mammalian genetics, waste R&D, global sciences, and energy efficiency.

Center for Biological Sciences

All of the Biology Division's existing facilities are badly aged, inefficient, and increasingly difficult to maintain; as a continuing (and worsening) drain on resources, they pose an urgent threat to ORNL's ability to sustain its high-caliber biological research. The Center for Biological Sciences will allow us to take critical steps both toward protecting our research investment and toward meeting Admiral Watkins' environmental-compliance goals in a cost-effective way. The new

Table 5. Budget projections[a] by fiscal year for the Center for Global Environmental Studies

	1990	1991	1992	1993	1994	1995	1996
Operating	6	8	9	10	11	11	11
Capital	0.1	0.1	0.1	0.1	0.1	0.1	0.1

[a]Includes university subcontracts; approximately 80% of funding would come from DOE, with the remaining 20% from non-DOE funding.

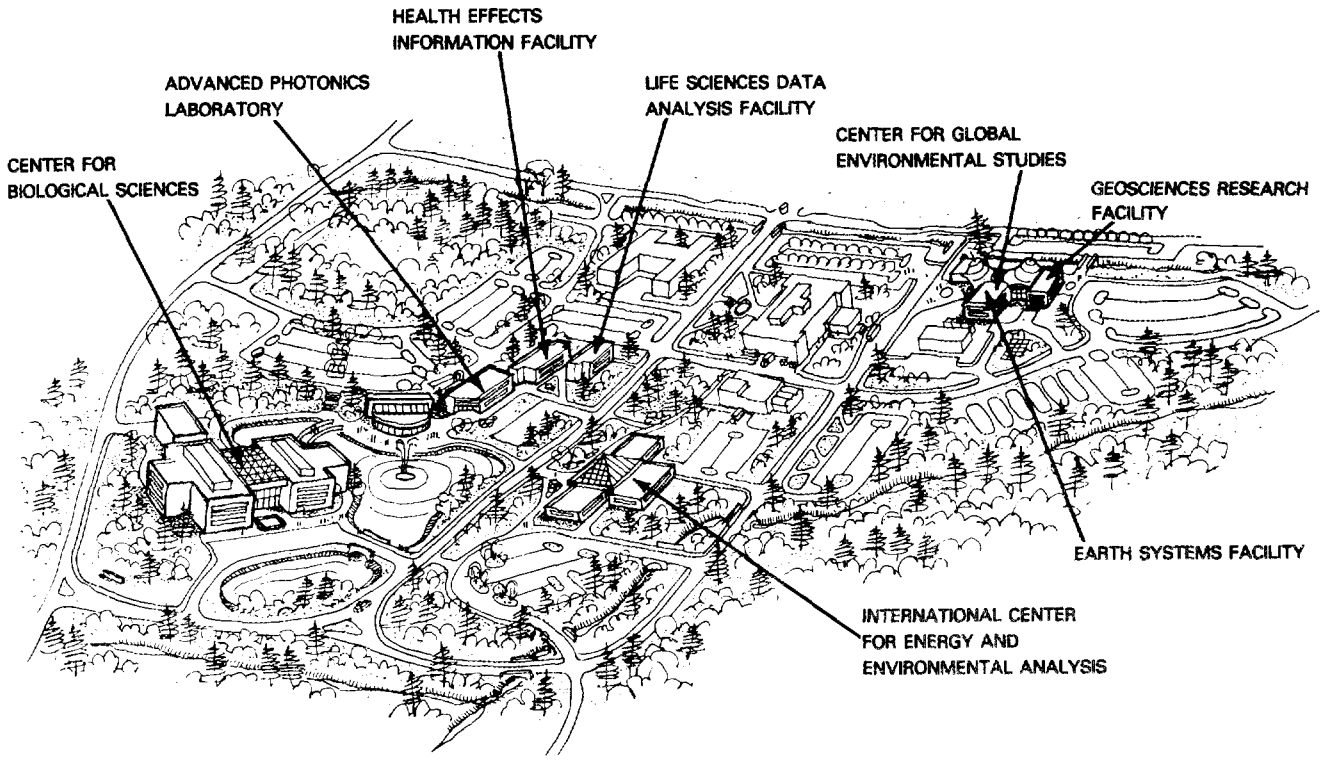


Fig. 9. Conceptual plan for the ORNL Life Sciences Complex (west end).

Center, located at the Laboratory's main site, will bring our user-oriented research out from "behind the fence" and into the open academic community, where collaboration and interactions with researchers from throughout the world can flourish.

The Center for Biological Sciences will bring together the following key components, allowing new interactions and synergies.

Transgenic Mouse Facility

This facility is a world-class center for producing and breeding new mutant mouse strains. ORNL is a leader in producing transgenic mice with insertional mutations—mutations triggered by inserting foreign deoxyribonucleic acid (DNA) "markers" into mouse zygote chromosomes. Some transgenic mice exhibit mutations that can be correlated with disease-producing mutations in humans. By developing many lines of transgenic mice, ORNL's breeding center will give researchers throughout the world powerful tools for deciphering the structure and function of the human genome.

Macromolecular Mapping and Engineering Facility

This user facility, coupled with ORNL's existing research reactors and the planned ANS, will allow researchers from universities and other institutions throughout the world to probe the three-dimensional structure of proteins and other complex hydrogen-containing molecules. It will also shed light on protein function through studies of "designer proteins" created by genetic engineering. This facility will reveal a new level of molecular detail, inaccessible to X-ray techniques

and beyond the reach of today's neutron-scattering equipment.

Bioprocessing Research Facility

This biotechnology user facility, already housed at the Laboratory's main site, develops advanced bioreactor systems to convert biomass into fuels and chemicals, to turn conventional fossil fuels into clean-burning liquids and gases, and to treat solid, liquid, and gaseous wastes. By bringing the Laboratory's biological researchers and analytical equipment into closer contact with the bioprocessing facility, we will forge strong new bonds, both within the Laboratory itself and with additional guest researchers from universities and industries.

Mouse Breeding Center for Human-Disease Models

In addition to breeding transgenic mice, the new facilities will house a center for breeding other mutant mouse strains, including strains mutated by radiation and chemicals. These mutant strains will provide animal models for exploring serious human diseases, including skeletal deformities, kidney disease, some forms of diabetes, and immune-system malfunctions such as arthritis and acquired immune deficiency syndrome (AIDS).

Advanced Photonics Laboratory

The Advanced Photonics Laboratory (APL) will serve as a focal point for integrating currently diverse activities involving photonic devices such as lasers, fiber optics, spectrometers, and detectors. Such devices are increasingly used in characterizing and monitoring during energy production, in defense operations, and in DOE's accelerated program for environmental restoration and waste management and biological research. The entire field of photonics is in a state of flux, with rapid advances in rugged and inexpensive solid state lasers with increased and new frequency capabilities. New phenomena in nonlinear optics, developing spectroscopic approaches such as surface-enhanced and Raman and X-ray microholography, are ripe for exploiting and applying to areas such as robotics, in situ fiber-optic sensing of contaminants in the subsurface environment, and rapid identification and resolution of base units in sequencing the human genome. The APL will act as catalyst and critical mass for accelerating these advances and producing new techniques and devices that will bear on specific DOE problems and new DOE initiatives.

The facility will bring diverse scientists into close contact while developing new lasers, fiber optics, spectroscopic systems, and field monitoring devices. The laboratory rooms will house lasers, optical benches, instrumental assembly and testing facilities, and facilities for simulating environmental test situations with attendant environmental chambers and the necessities for validation and intercomparison testing. Multiagency activities will be accommodated in the APL. The laboratory space and flexibility of design and layout will be ideal for expansion of such activities as DOE programs in environmental restoration and waste management and human genome studies; DOD programs in installation restoration and weapon reduction, destruction, and verification; and EPA's Environmental Systems laboratories programs in hazardous waste.

Earth Systems Facility

For the next several decades, the global environment will be center stage. The analysis of global environmental issues and the necessity to regulate the global commons will stage the world for international environmental debates. To manage international disagreements, integrating analyses of biophysical, social, and economic considerations must be merged through earth systems models to bridge the interdisciplinary gaps that prevent us from understanding the earth as a

set of complex and interacting systems. To assist in this goal, it is time for ORNL to consolidate the interdisciplinary talents of ORNL researchers in global change. It is time for ORNL to build and promote the interdisciplinary teams that can tackle the long-range goal of building an earth systems model. It is time for us to combine an integrating facility with our world-class global change researchers.

By establishing the Earth Systems Facility, ORNL will continue to play a pivotal role in the advancement of understanding earth systems. The facility will be structured, physically and organizationally, to promote accessibility, collaborative research, and user interactions. As a result, the facility itself will become a powerful new tool for bringing ORNL's scientific expertise to help guide management of the planet on which we live.

This project will provide ~25,000 ft^2 of space in the 1500 area of the Laboratory to house an Earth Systems Facility that will support research in the environmental sciences and the earth sciences. The multiuse facility will have computational and limited experimental capabilities for biogeochemical modeling, solid earth processes, climatology and hydrology, geographic information system (GIS)/mapping, and data systems. The facility will support the large-scale studies of geosciences, ecology, and environmental sciences needed to develop interdisciplinary earth system models for evaluating whole-earth processes associated with global change.

Budget Requirements

Conceptual design is in preparation for the proposed Center for Biological Sciences as an FY 1993 line-item construction project. The Center, the first step in relocating the entire Biology Division, will provide the resources required for advanced-level molecular genetics research. The buildings will be a cost-effective modular design, with one-time engineering and design costs. In addition to the estimated $63.6 million in Environmental Research and Development (KP) program construction, investments are planned of approximately $1 million in program overhead to support projects, about $7.3 million in GPP projects in the Life Sciences Complex, $29 million in general purpose facilities located in the complex, and $4 million in other construction funds. Table 6 provides a detailed budget breakdown of the proposed Life Sciences Complex development.

Waste R&D Initiatives

Basic Science R&D in Support of Environmental Restoration

In the last few years the magnitude of the environmental restoration effort directed toward cleanup of DOE's legacy of contaminated sites has been realized. Vast resources will be devoted to this issue; estimates are on the order of $100 billion. Fortunately, there are many situations that can be effectively addressed with available technology so rapid progress can be achieved. There are many other cases, however, in which our level of understanding of the complex systems associated with remediation of disposal sites and the environmental behavior of wastes is either nonexistent or poorly developed, resulting in the need for development of an appropriate base of knowledge. This latter challenge demands foresight in identifying future needs as well as a relatively long-term commitment toward research directed at fundamental basic science issues related to environmental restoration; goals of this effort are laid out in terms of several decades, rather than a few years. It is apparent that leadership in this area of basic R&D must rapidly evolve and must integrate multidisciplinary science into a focused program that strives to develop the fundamental knowledge base that will be required to allow the DOE efforts at restoration to be successfully undertaken in a cost-effective and environmentally

Table 6. Budget projections by fiscal year for the Life Sciences Complex development
($ in millions)

	1989	1990	1991	1992	1993	1994	1995	1996	Total estimated cost
	O[a]	O/C[b]	O/C	O/C	O/C	O/C	O/C	O/C	
Program KP									
Center for Biological Sciences		0.15/0	0.8/0	0/0	0/4.0	0/20.0	0/20.0	0/3.9	48.85[c]
Advanced Photonics Lab						0/1.5	0/5.2		6.7
Earth Systems Facility						0/2.0	0/7.0		9.0
Total									64.55
Program AT (GPP)									
Data Analysis Facility	0.06	0/1.2							1.2
West-end utility extension, phase I	0.04	0/1.2							1.2
West roads and parking improvements			0/0.1						0.1
Health Effects Information Facility				0/1.2					1.2
Geosciences Research Lab				0/1.2					1.2
West-end utility extension, phase II					0.04/0	0/1.2			1.2
Global Environmental Studies Center						0/1.2			1.2
Total									7.3
Other construction[d]									
International Center for Energy and Environmental Analysis			0/0.54	0/0.78	0/1.02	0/0.72	0/0.72	0/0.48	4.26
Program KG (Capital costs only)									
Steam system upgrade, west end				1.1	6.0	1.9			9.0
Radiation Exposure Assessment Lab					3.0	9.0	8.0		20.0
Total									33.26

[a]O = operating.
[b]C = capital.
[c]Planned for lease purchase (operating funds) or potential GPP construction (AT capital funds).

safe fashion. Basic R&D support today will help ensure timely, cost-effective methodologies for tomorrow.

This basic R&D challenge is to be developed for addressing the following broad objectives that are representative of the foundation of a sophisticated understanding of long-term needs for environmental restoration:

- understanding the biological, physical, and chemical factors that control the movement and

chemical transformations of radioactive, hazardous, and mixed wastes in the subsurface and surface water systems;

- achieving the capability to quantitatively model contaminant movement in the environment;
- developing new remediation technologies (physical, chemical, and biological) for environmental restoration and recommendations for future waste management;
- assessing the impact of remediation on human and environmental health;
- developing and validating new models for assessing the health and environmental risks associated with historic, current, and planned disposal operations; and
- developing performance assessments and post-remediation technologies and capabilities.

These broad objectives will demand a wide variety of technical disciplines as well as a highly interactive structure in which to operate. For example, significant emphasis must be placed on modeling capabilities, including those related to geochemistry and hydrology as well as to risk analysis, and on the development of fundamental data bases that can support the models. The interactive relationships between wastes of different types and natural processes of varying nature must be studied. Emphasis must be placed on microbial transformations that can be utilized in remediation as well as on other biological parameters that can effectively serve as risk and performance assessment evaluators. Inherent in this initiative will be the need for enhanced computational capability and the use of artificial intelligence and expert systems as means for aiding restoration decisions. The identification of basic research issues of importance to the waste R&D effort will change as technologies develop and as new problems are encountered.

The necessity of having an initiative that focuses specifically on issues that require a relatively long lead time and that are not specifically directed at resolution of a pressing problem is evident if the environmental restoration efforts of DOE are to be met effectively. It is expected that there will be increased attention given to this need, and it is an opportune time for ORNL to take advantage of its multidisciplinary expertise and experience in waste R&D in developing this area. The setting of ORNL and the functional relationship with other DOE plants in the humid eastern United States provide a unique opportunity for field testing of assorted projects ranging all the way from characterization to remediation. Indeed, this initiative would involve multiple divisions within the Laboratory structure and would keep ORNL at the cutting edge of an area that is rapidly expanding.

As a basic science initiative, this component of the waste R&D initiatives is specifically addressed to the Office of Energy Research. Budget projections are provided in Table 7.

Table 7. Budget projections by fiscal year for the Basic Science R&D component of the Waste R&D Initiatives ($ in millions)

	1990	1991	1992	1993	1994	1995	1996
Operating	0.2	0.6	1.5	2.8	4.5	5.5	6.3
Capital	0.0	0.2	0.5	0.8	1.0	1.2	1.2

Applied R&D Component of the Waste R&D Initiatives

The Applied R&D Component of the Waste R&D Initiatives is proposed specifically to DOE's Office of Environmental Restoration and Waste

Management (EM), which was recently created to deal with the past, present, and future wastes at federal facilities. Within this organization is the Office of Technology Development (OTD), which is charged with maintaining an aggressive applied research, development, demonstration, testing, and evaluation program. Successful application of technology developed for OTD will be used in remediating federal facilities, with an emphasis on transfer of appropriate technology to the private sector. Because all aspects of the organization of EM were not completed at the beginning of FY 1990, funding for FY 1990 OTD work came through budget and reporting (B&R) codes GF72 and GF73; FY 1991 funding and beyond will come through B&R code EW40. The nature and visibility of waste management issues indicate that a very aggressive program and growth rate are necessary and appropriate. The incremental budget for the Applied R&D Initiative is shown in Table 8.

Because a large investment is required to remediate environmental insults at the DOE facilities, a vigorous R&D program is needed to minimize cleanup costs, to quantitatively understand the risks posed by the contaminated sites, and to help establish priorities. The purpose of this Waste R&D Initiative at ORNL is to research, develop, and demonstrate advanced technologies that will significantly reduce the costs of environmental restoration and waste management while meeting current (and future) regulatory requirements in a manner acceptable to the public.

One component of this multifaceted program is to determine methods or develop techniques to identify and characterize the wastes and waste sites associated with the various DOE facility operations, particularly those within the eastern half of the United States. As part of this characterization effort, more useful tools need to be developed to respond to compliance requirements at minimal cost:

- developing chemical- and biological-based solutions to waste problems;
- modeling of hydrologic systems;
- developing advanced field measurement and sensing techniques;
- improving methods for data collection, analysis, management, and display;
- understanding contaminant behavior and response to remediation techniques and improved, less costly analytical techniques in situ and real time; and
- developing field-oriented methods that allow both site and contaminant characterization with minimal cost and health/safety impact.

A second component of the Applied Waste R&D Initiative involves assessment of existing waste management methods and evaluation, development, and demonstration of new potential technologies for waste treatment. Some of these potential technologies may currently be in use in other industries, but they have not been considered for applicability to waste management. These technologies need to address all three frontiers of restoration and waste management: (1) cleanup (remediation) of existing contaminated sites; (2) better techniques for handling wastes currently being generated; and (3) process modifications to minimize future waste generation. The technologies currently being evaluated and developed include the following:

- bioremediation/biotechnology—microorganisms that can fix, degrade, detoxify, or accumulate organic and selected inorganic species in situ or in process;
- robotics—robotic systems and remote technology that can enhance environmental restoration and waste management operations by removing workers from hazardous materials, increasing speed and productivity of operations, and reducing life-cycle costs (Fig. 10);
- waste minimization—waste reduction in volume and/or toxicity through techniques ranging from fundamental chemical reactions to engineering and process redesign;
- in situ stabilization—waste treatment in situ to reduce their environmental insult; and
- advanced separations technologies—waste concentration to permit more effective and efficient management.

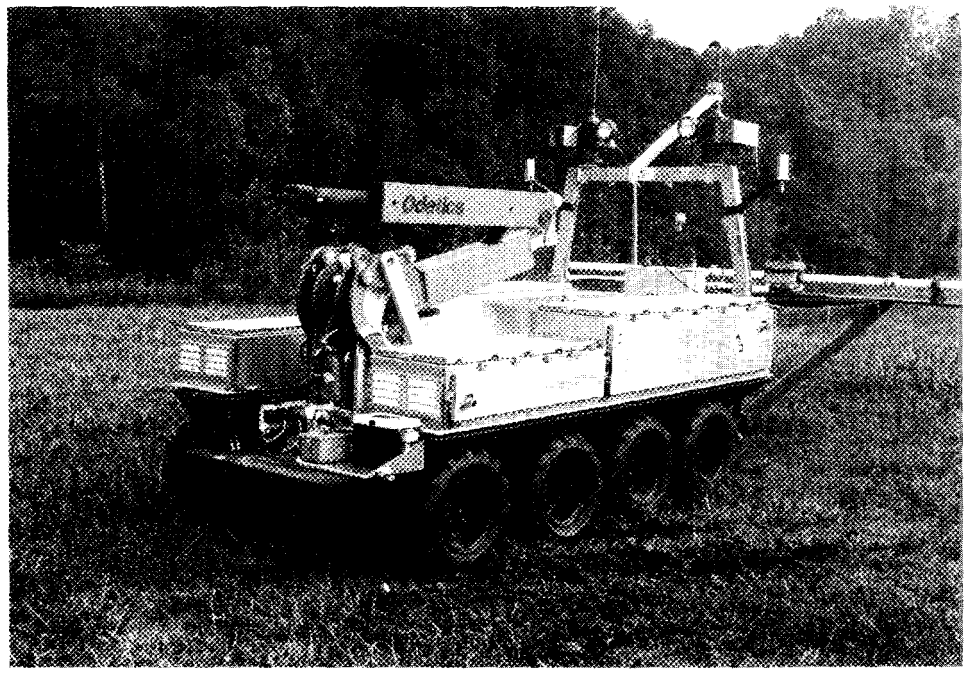


Fig. 10. Accurate characterization of waste sites is the first step in a safer, faster, less costly remediation of the environment. An existing remotely operable vehicle (developed by the Department of Defense) has been modified and further developed by ORNL, using ORNL-developed Ultrasonic Ranging and Data System (USRADS) technology, for a demonstration of remote semiautonomous survey and characterization of a buried waste site. USRADS is also being used to survey the 170-acre ORNL X-10 site to measure and map contamination and radiation levels and to identify suspect burial sites.

Although the technologies listed above are, to some extent, currently developed, much more refinement and advancement are necessary to allow them to be cost-effective for the increasingly more challenging waste problems. It is expected that there will be significant industrial involvement in this component of the program, particularly in the demonstration phase, thus requiring an efficient transfer of new technologies for applications both within and outside the DOE facilities.

Concern over the lack of qualified, trained scientists and engineers to solve future problems has led to an increased emphasis on education at DOE. ORNL is responding to the concern by developing joint research projects with universities and historically black colleges and universities to encourage students to study in fields applicable to waste management.

Budget projections for OTD programs are given in Table 8.

Table 8. Budget projections by fiscal year for the Office of Technology Development programs ($ in millions)

	1990	1991	1992	1993	1994	1995	1996
Operating	10	8	14	19	21	25	28
Capital	0	2	2	2	2	2	2

Gammasphere

Gammasphere is a national gamma-ray facility that will be used for a broad range of nuclear physics experiments. It consists of an array of 110 large-volume high-purity germanium detectors surrounded by 360 scintillator detectors made of bismuth germanate and arranged in a large spherical honeycomb design to cover a 4π solid angle with the symmetry of an icosahedron (Fig. 11). The array detects nuclear radiation produced by bombardment of a thin-film target with energetic heavy-ion beams such as those produced at the ORNL Holifield Heavy Ion Research Facility (HHIRF). The current design allows for replacement of germanium detectors in the forward hemisphere with 55 barium-fluoride detectors when the array is to be optimized for high-energy gamma-ray detection.

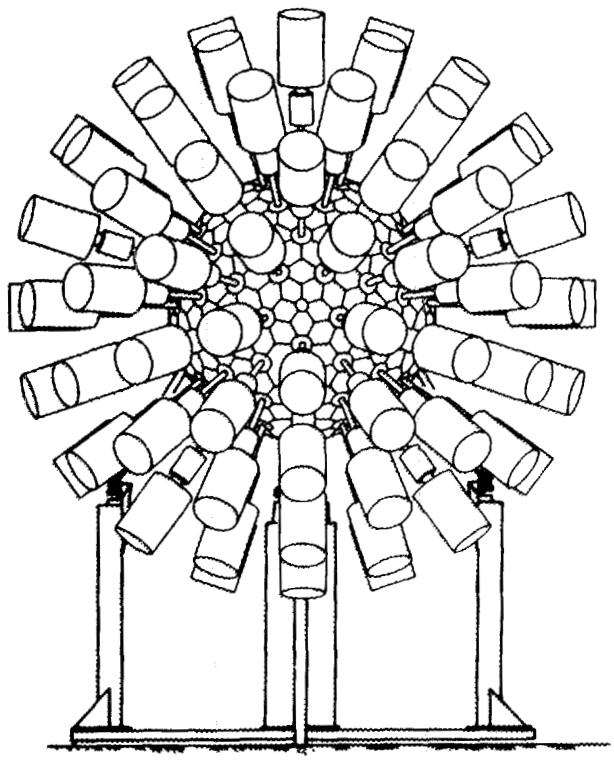


Fig. 11. Sketch of the Gammasphere detector system.

Gammasphere has been proposed as a national facility by scientists from several national laboratories who have collaborated in the design of the new instrument. Gammasphere will cost approximately $17 million and will be funded by the Division of Nuclear Physics of DOE's Office of Energy Research. A DOE review panel has recommended that this device be placed at ORNL. If ORNL is affirmed by DOE as the site for Gammasphere, it will be located at the HHIRF. HHIRF building modifications of approximately $1.1 million will be provided out of ORNL GPP funds to accommodate the detector system. Construction funds for Gammasphere are requested for the FY 1991–1993 period with operation to begin in FY 1994 (Table 9).

Heavy-Ion Storage Ring for Atomic Physics

The Heavy-Ion Storage Ring for Atomic Physics (HISTRAP), a 2.7-T-m synchrotron/cooler/storage ring, has been an ORNL initiative for several years. The study of

Table 9. Budget projections by fiscal year for the Gammasphere ($ in millions)

	1990	1991	1992	1993	1994	1995	1996
Operating	0.2	0.2	0.3	0.4	1.1	1.1	1.1
Capital					0.2	0.2	0.2
GPP construction		1.1					
Line-item capital		5.5	6.0	5.5			

multiply-charged-ion physics is a major effort at ORNL, other DOE facilities, and many universities. Many important aspects of multiply-charged-ion science are not accessible with existing facilities because of low-beam currents, large-beam emittances, or short-interaction times. These limitations can be overcome by the use of a synchrotron accelerator that can either accelerate or decelerate heavy-ion beams; provide electron-beam cooling of the ion beam to decrease beam emittance and energy spread; and store the resulting circulating beam for in-ring experiments with fixed targets or with merged electron, photon, and ion beams. A committee, appointed by the National Research Council of the National Academy of Sciences, has studied the need for such a facility and has given a strong positive recommendation to the HISTRAP. In early 1989, a review committee sponsored by DOE-BES evaluated competing atomic physics facility proposals and strongly recommended the ORNL HISTRAP proposal for DOE approval and immediate construction. The importance of such a facility for the national program in atomic physics was reaffirmed by a DOE-appointed program review panel in late 1989.

The proposed HISTRAP facility will be associated with the HHIRF, a national user facility. HISTRAP could operate using the HHIRF Tandem Accelerator as a high-energy heavy-ion injector source or with a separate low-energy electron cyclotron resonance source. Nearly $900,000 of ORNL funds were used from FY 1987 to FY 1989 for design and prototype construction of three difficult and long-lead-time major components of the device: dipole magnets, vacuum systems, and rf cavities. It is essential for beam quality and storage to maintain an ultrahigh vacuum in the HISTRAP ring. Therefore, a vacuum test-stand, modeling one-half of one straight section (1/16) of the proposed octagonal ring, was assembled and used to demonstrate the best vacuum ever attained in the western hemisphere, 3×10^{-12} torr. The HISTRAP design calls for an rf cavity capable of a wide frequency swing; hence, a ferrite-loaded wide-band prototype rf cavity was designed, built, and tested that achieved a frequency swing from 0.2 to 2.7 MHz. Also, a prototype dipole magnet was designed at ORNL, fabricated by the Fermi National Accelerator Laboratory magnet factory, and installed and measured at ORNL. The measured magnetic field quality is adequate for the dipole to be used in HISTRAP without alteration. Thus, ORNL is well positioned for production of several of the essential components of the HISTRAP. Construction of the HISTRAP is requested for FY 1992, with a cost estimate of $18.5 million (Table 10).

Table 10. Line-item construction budget by fiscal year for the Heavy-Ion Storage Ring for Atomic Physics ($ in millions)

	1992	1993	1994	Estimated cost
Total	8.3	6.9	4.4	19.6

Grand Challenges in Computational Science

High-speed, large-scale computation has become the primary enabling technology for advanced research in many areas of science and engineering. Because of physical constraints and/or costs, computer simulations are the only feasible manner in which detailed research investigations on many complex phenomena can be performed. The number of investigations requiring such computer experimentation is rapidly increasing as scientists probe deeper into the understanding of small systems such as subatomic particles as well as large systems such as global climate. Thus, computation has become an equal partner with theory and experiment in advancing the frontiers of knowledge. The exploitation of massive parallelism is expected to bring the next major increment in computational capacity that will be

necessary for attacking the "grand challenges" of computational science. The solutions to these fundamental problems are of great importance to science and engineering; they will require breakthroughs in computer architectures and algorithms and in how these can be brought to bear on specific applications.

To address these issues, ORNL proposes this initiative, which is focused on solving selected grand challenges in computational science. The initiative would take advantage of unique resources at ORNL and other regional research institutions to provide the combination of research expertise in parallel computing, expert scientists and engineers with computing intensive applications, parallel computing hardware, and high-speed fiber networks necessary to solve important computational problems in science and engineering. In addition to the base of expertise and equipment located at ORNL, such large scientific and engineering institutions as the University of Tennessee, Knoxville (UTK), Vanderbilt University, Tennessee Technological University, and the Tennessee Valley Authority (TVA) would add complementary capabilities.

The selection of grand challenges to address would be based on four criteria:

- The problem is of fundamental importance, and its solution would be of great value to science.
- For adequate accuracy and resolution, the problem requires massive computation, well beyond the capacity of today's supercomputers.
- The problem is amenable to the effective exploitation of massive parallelism.
- ORNL, together with other regional research institutions, is in a position to make significant progress on the problem.

ORNL, as a multipurpose national laboratory, has several research problems that satisfy the above criteria. A partial listing of these potential grand challenges include the following:

- calculation from first principles of the physical properties of high T_c superconductors;
- global climate modeling;
- design and analysis of particle detectors for the Superconducting Super Collider (SSC);
- investigations of quantum electrodynamical phenomena in atomic/nuclear physics;
- fluid flow through porous media incorporating geology, physics, and biochemistry for modeling environmental cleanup problems; and
- fusion energy modeling.

Grand challenges will be added in the initiative as long as sufficient resources are available.

ORNL already has in place the core personnel to form interdisciplinary teams to carry out many grand challenge projects. Expertise in parallel computing research exists in the Mathematical Sciences Section of the Engineering Physics and Mathematics Division as well as in several other groups and divisions. There are also many specialists at the Laboratory in the particular applied disciplines that would be involved who already have the necessary interest and experience in large-scale computations, even large-scale parallel computations. Significant collaboration also currently exists between researchers at ORNL and UTK. A Joint Institute for Computational Science, which complements this initiative, has been proposed by UTK and is expected to become a reality in the near future.

ORNL has one of today's fastest supercomputers in the 128-processor Intel iPSC/860, peak rated at 10 gigaflops (32-bit arithmetic) and 7.6 gigaflops (64-bit arithmetic). Less powerful versions of other parallel computers with fundamentally different architectures are also available at ORNL and UTK. These computers are suitable for pilot implementations and architectural comparisons for specific applications, and they are accessible by researchers across the nation via all major computer networks (NSFnet, ESnet, MFEnet, BITnet, etc.). It is planned to make them regionally available via a high-speed fiber optic network. Through these same network connections, researchers involved in the initiative can access parallel computers at other national computer centers and research organizations.

Preliminary studies of the type envisioned have already begun under support from various DOE research programs. Pilot projects designed to

gain a better fundamental understanding of high-temperature superconductors and lepton-pair production in atomic physics are currently being implemented by interdisciplinary teams from the Mathematical Sciences Section, the Metals and Ceramics Division, and the Physics Division of ORNL. Projects have also been initiated in climate modeling and fusion energy calculations. These projects have made excellent progress in implementing real application codes on ORNL's Intel parallel supercomputer. A code to compute the density of states for real superconductors is running at 2 gigaflops—the highest speed on a real application code advertised by a computer vender.

The initiative expects to expand significantly the leadership that ORNL has achieved in this field. Interdisciplinary, interagency teams of senior scientists will be augmented by postdoctorates, graduate students, and distinguished visitors. New high-performance, "early-production" parallel supercomputers will be procured in a systemic manner as they become available and will significantly add to the capabilities of the initiative. Connections to new high-speed national research and production networks will be pursued. A new building to house the various components and to provide a central location for the initiative's diverse activities will also be sought.

A number of studies and reports by distinguished panels of experts have recognized the critical importance of large-scale computation to the scientific and economic competitiveness of the United States. A number of federal funding agencies, including DOE, have expressed an interest in establishing centers for intensive research in this area. The state of Tennessee has recognized the need to provide the faculty and students at their universities with access to high-performance parallel computers and to interaction with researchers who are actively involved in their use on scientific and engineering problems. Many industrial companies, including Intel Scientific Computers, Inc.; IBM Corporation; and Digital Equipment Corporation, have expressed interest in supporting such a computational science initiative. TVA has also indicated interest in participating. All of these agencies and institutions will be solicited for their participation.

Total budget projections for this initiative are provided in Table 11. Large computer equipment will likely be purchased with operating funds under a lease-to-ownership arrangement.

Materials Science and Engineering Complex

The ORNL Materials Science and Engineering (MS&E) Complex will consolidate a number of existing ORNL programs and incorporate new buildings and facilities to enhance collaborative interactions in MS&E. The complex will be constructed in the early 1990s in the undeveloped foothills area to the east of the present X-10 site (Fig. 12). The MS&E complex will include a new Solid State Sciences Building, a Center for Advanced Microstructural Analysis, a Center for Study of Advanced Materials, a Composite Materials Laboratory, and an Office of Guest and User Interactions (OGUI). The plan of

Table 11. Budget projections by fiscal year for Grand Challenges in Computational Sciences ($ in millions)

	1989	1990	1991	1992	1993	1994	1995	1996
Operating	0.4	1.6	4.0	25.0	15.0	15.0	20.0	20.0
Capital	0.3	0.3	0.5	1.0	1.0	0.5	0.5	0.5

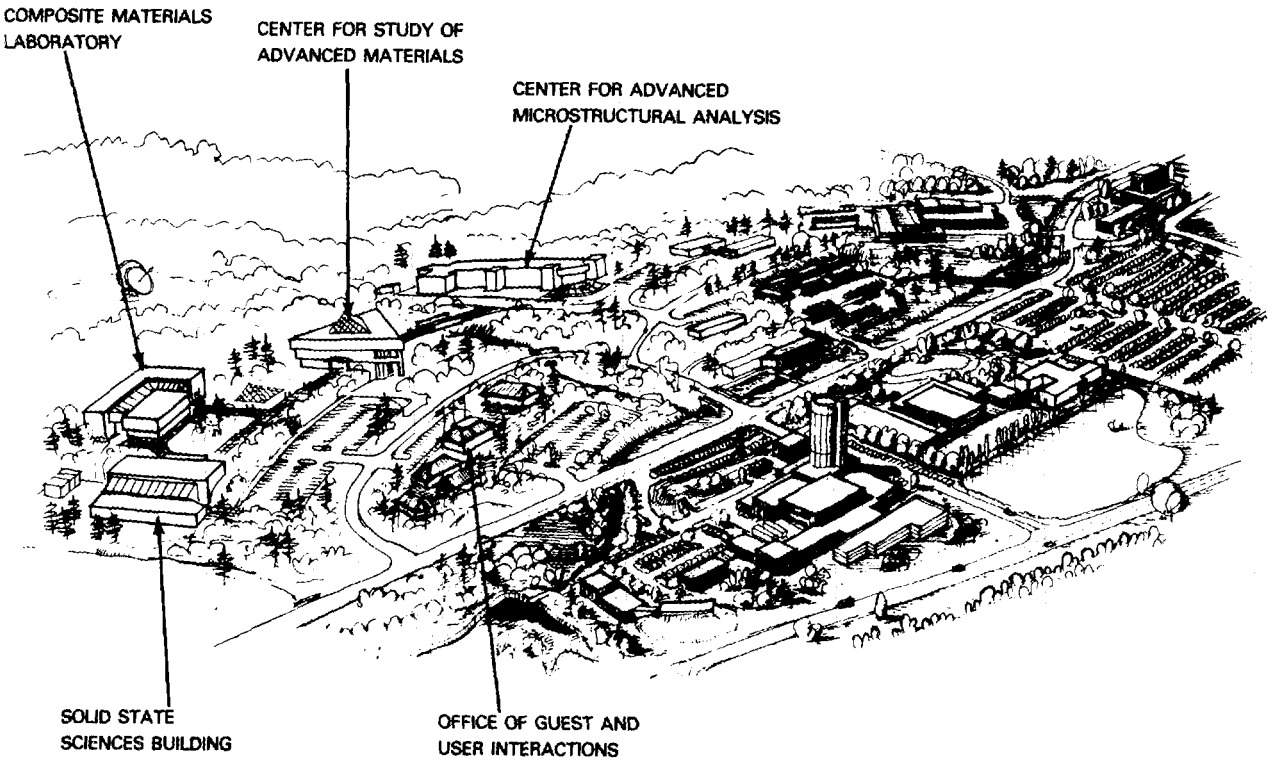


Fig. 12. Proposed Materials Science and Engineering Complex to be constructed east of the present X-10 site.

the complex addresses identified national, regional, and local needs for materials R&D, and it will support ORNL's rapidly expanding user programs and technology transfer activities. The existing OGUI will be sited in the complex to coordinate the administration of ORNL's many user activities. The Center for Study of Advanced Materials is an initiative of the Southeastern Universities Research Association (SURA) that will encourage joint materials research activities with ORNL by establishing a university/industry presence at the MS&E Complex.

The MS&E Complex also meets a critical need to replace deteriorated buildings and to alleviate severe crowding in materials facilities at ORNL. The need to replace substandard Solid State Division laboratories has been recognized for decades, and during this time their condition has considerably worsened. The Solid State Sciences Building will satisfy the need for modern solid state laboratories at substantially lower cost than refurbishing existing structures to meet present Environment, Safety, and Health and Occupational Safety and Health Administration standards. The Microstructural Analysis Center is a response to the need for buildings capable of housing the next generation of instrumentation with vibration-sensitive electron optics. A new building will house such instrumentation and also bring together under one roof a full range of modern microanalytical instrumentation. The added space will alleviate severely overcrowded conditions in the Metals and Ceramics Division.

A recent study by the National Research Council, *Materials Science and Engineering for the 1990s*, demonstrates that materials science and engineering is among the most rapidly developing areas of science and is an area that is vital to the future competitiveness of the United States in the international marketplace. Over the past decade, it

has become increasingly clear that the need is not only for cutting-edge research but also for the close cooperation among universities, industries, and national laboratories that can rapidly carry ideas from inception to the marketplace. As a follow-on to the National Research Council MS&E study, the Office of Science and Technology Policy is drafting a national plan for MS&E to promote and coordinate this area to meet the nation's future needs. ORNL will structure the MS&E Complex to coordinate with that plan.

Materials R&D is the cornerstone of high technology, and ORNL has one of the strongest materials programs among the DOE national laboratories. Indeed, the ORNL programs in high-temperature alloys, ceramics, composites, and superconductors are unparalleled successes. ORNL is also a leader in user programs and technology transfer through collaborative research agreements and licensing. These activities have grown rapidly and will increase even faster because of recent congressional legislation removing barriers to technology transfer.

The MS&E Complex is a recognition of the dual need to perform and to exploit materials R&D in the changing conditions of the 1990s. The MS&E Complex will not only provide ORNL with a much-needed replacement and expansion of its materials R&D facilities, but it will also provide the cooperative environment that will enhance R&D effectiveness and promote technology transfer. Marketplace success requires the active participation of U.S. industry. Industry must guide and participate in the research, development, and manufacturing science activities. The nation's competitiveness can be enhanced by taking advantage of the technology transfer opportunities emanating from universities and national laboratories. Industry can make use of our wide-ranging multidisciplinary skills: our fabrication, characterization, and test capability; our independent, objective, no-vested interest outlook; and our ability to work with and protect proprietary information.

Universities and colleges in the southeastern part of the United States have numerous innovative materials R&D programs that collectively span a broad range of disciplines from materials chemistry to materials physics to materials engineering and testing. During the last few years, SURA and the Oak Ridge Associated Universities (ORAU) have explored ways to simplify and encourage joint materials research activities with ORNL. This approach would not only benefit large, well-established programs but also would enhance individual small programs at the universities through synergistic interactions. A close working relationship between UTK and ORNL is already well established. Faculty and graduate students from UTK participate in collaborative research with the staff at ORNL, and the staff at ORNL serve as adjunct professors and thesis advisors at UTK.

Center for Study of Advanced Materials

As the result of a SURA materials science workshop and other organizational meetings between SURA and ORAU, the establishment of a campus-like presence at ORNL in the form of a Center for Study of Advanced Materials (CSAM) for materials science and engineering has been proposed as a means to increase the materials impact of the member universities (Fig. 13). The goals of CSAM would be to develop broadly based scientific initiatives in materials science and engineering that would reflect the special talents, facilities, and capabilities residing in the Southeast. These initiatives would address nationally significant problems that are important to both DOE and the university participants and that transcend the capabilities of a given institution. A proposal is being developed for CSAM which would support the ongoing research and graduate education programs of the southeastern universities by providing a site at ORNL where students and faculty could be located while participating in joint research; by utilizing ORNL user facilities and staff; by holding workshops; and by otherwise benefiting from enhanced interaction with other university, industry, and national laboratory

Fig. 13. Conceptual drawing of the Center for the Study of Advanced Materials.

researchers. The center is intended to integrate and enhance the entire spectrum of materials science and engineering opportunities at ORNL and make them accessible to the southeastern institutions. The SURA communications network would be tied into CSAM to provide scientific interchange through broadcasts of seminars, lecture series, workshops, and other significant technical presentations or discussions.

The operation of CSAM would be carried out through the cooperation of SURA, ORAU, and ORNL. An informal summer program was started at ORNL in 1989 for faculty and graduate students from southeastern universities. The cost is shared by ORNL and the participating universities. Support for CSAM is envisioned as joint funding from DOE-BES, the NSF Division of Materials Research, state funds from the participating universities, and industry partnerships. Establishment of CSAM would involve construction of a building adjacent to ORNL at an approximate cost of $16 million, with projected operating costs of $4 to $5 million per year. Budget projections are provided in Table 12.

Solid State Sciences Building

The Solid State Sciences Building (Fig. 14) will allow the research activities that are presently located in 15 separate buildings to be consolidated into a central facility as part of the MS&E Complex. The 80,000 ft^2 building will provide approximately 100 offices and 40 laboratories for state-of-the-art materials research and development. The new facility will replace aging facilities that cannot be upgraded to accommodate modern research or to comply with ES&H

Table 12. Budget projections by fiscal year for the Center for Study of Advanced Materials ($ in millions)

	1990	1991	1992	1993	1994	1995	1996
Operating	0.5	1.0	2.0	3.0	4.0	4.5	4.5
Capital equipment			2.0	0.5	0.5	0.5	0.5
Line-item construction			2.0	14.0			

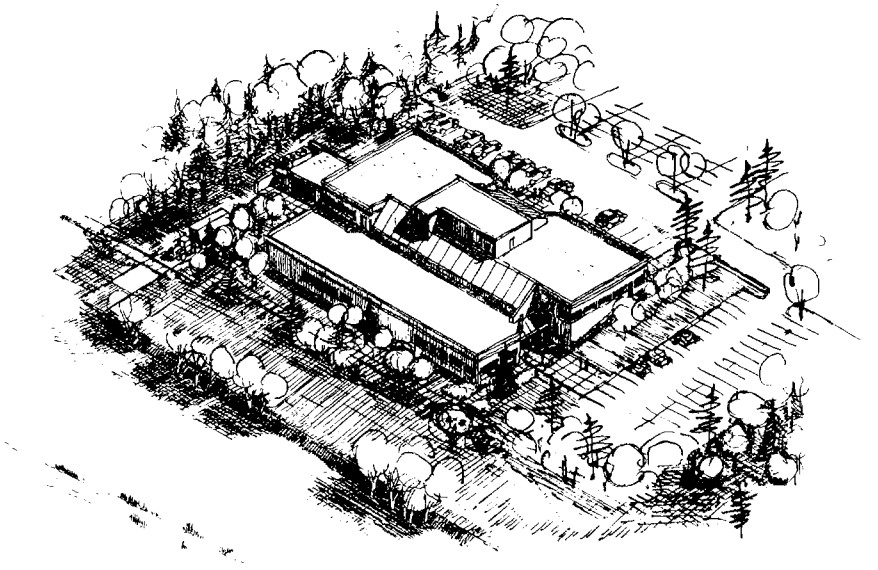


Fig. 14. Conceptual drawing of the Solid State Sciences Building.

standards at acceptable costs, and it will enhance the effectiveness of the solid state research program as part of the highly interactive MS&E Complex. Budget projections are provided in Table 13.

Table 13. Budget projections by fiscal year for the Solid State Sciences Building ($ in millions)

	1990	1991	1992	1993	1994	1995	1996	Total estimated cost
Line-item construction	0	0	0	0	3.5	14.5	10.0	28.0

Center for Advanced Microstructural Analysis

The Center for Advanced Microstructural Analysis will be a national resource for the user community (Fig. 15). As microanalytical instrumentation becomes more sensitive, performance is limited not by the instruments themselves but by the environment in which they are situated. Electromagnetic fields, building vibrations, and even low acoustic noise act to degrade performance. Most existing facilities were designed as general-purpose laboratories with little attention paid to the environmental issues that now restrict performance. The Center for Advanced Microstructural Analysis will provide a state-of-the-art site for location of the broad range of microanalytical instrumentation available at ORNL, including analytical and high-resolution electron microscopes, atom probes and field ion microscopes, surface analysis instrumentation, X-ray diffraction facilities, and mechanical property microprobes. Building services and even

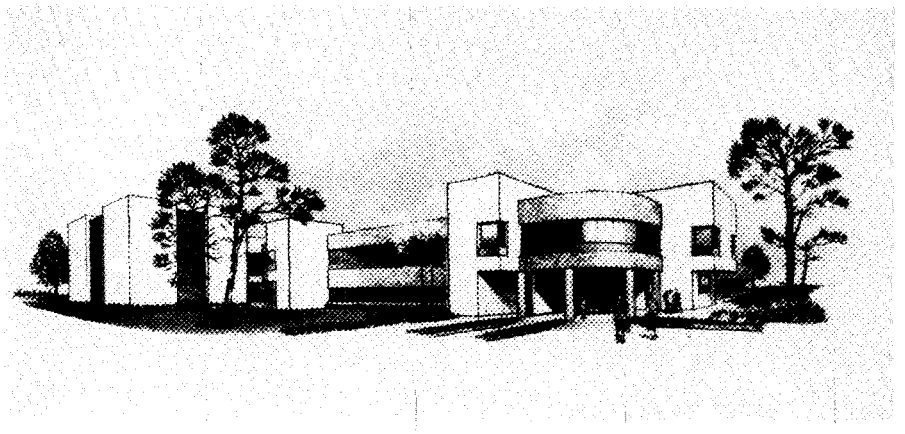


Fig. 15. Conceptual drawing of the Center for Advanced Microstructural Analysis.

traffic patterns will be routed to enhance the isolation of the most sensitive instruments. The design of the 52,000 ft^2 building will emphasize information management and allow for digital-image acquisition and processing. Provisions will be made for remote operation of many of the most sensitive instruments. The cost is currently estimated at $37.5 million. The design will be started at the beginning of FY 1993, and construction will be completed in FY 1996. Budget projections are provided in Table 14.

involved with composites are the Applied Technology Division, the Engineering Technology Division, and the Metals and Ceramics Division. Other Martin Marietta Energy Systems divisions with supportive specialties such as nondestructive evaluation and materials characterization are also expected to participate, and UTK will also contribute. The Center of Excellence for Materials Processing is the focal point for the composites research at UTK. The university departments involved in the composite research include

Table 14. Budget projections by fiscal year for the Center for Advanced Microstructural Analysis ($ in millions)

	1990	1991	1992	1993	1994	1995	1996
Capital equipment	0	0	0	0.5	1	2	1.5
Line-item construction	0	0	0	2	4	8	6

Composite Materials Laboratory

The Composite Materials Laboratory will build upon ORNL work on polymer, carbon-carbon, and metal and ceramic matrix composites that are found in several different organizations (Fig. 16). The principal ORNL divisions

Materials Science, Engineering Science and Mechanics, Mechanical and Aerospace Chemical Engineering, Chemistry, and Physics.

The composites R&D involves several technology areas: materials science and processing, mechanics, and prototype fabrication and evaluation, including nondestructive examination and testing and technology transfer. Materials

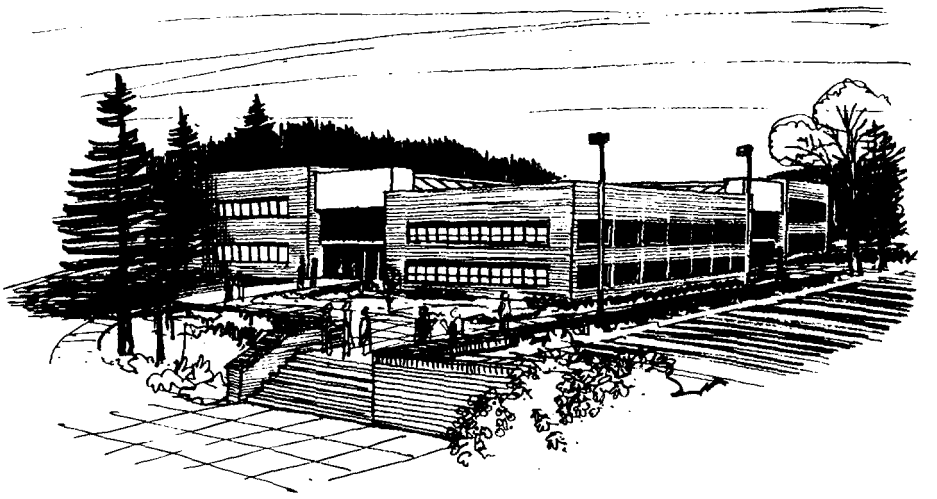


Fig. 16. Conceptual drawing of the Composite Materials Laboratory.

science and processing focus on properties of engineering materials appropriate for applications by controlling composition, molecular structure and microstructure, and process variables. ORNL and UTK have a unique R&D capability for analyzing the mechanical behavior of composite structures through a predictive failure theory based on concepts of fracture mechanics and basic thermodynamic principles, environmental effects, and on ORNL's extensive applied mechanics capabilities with attendant large-scale computing support. Collectively, this capability can relate microstructural properties to structural performance. Critical to the use of composites is the ability to detect and measure the size of defects by nondestructive examination, which will take advantage of the ORNL experience in the examination of composites using ultrasonics and penetrating radiation (primarily X-rays). State-of-the-art X-ray computer tomography equipment and a digital image analyzer for radiographs have significantly enhanced the capabilities of ORNL to evaluate composite materials.

The Composites Materials Laboratory is planned as a 50,000 ft^2 building that will house an interdisciplinary team of over 100 ORNL and university scientists, engineers, students, and supporting staff. Budget projections are provided in Table 15.

Office of Guest and User Interactions

The Office of Guest and User Interactions (OGUI) is the ORNL interface with a large

Table 15. Budget projections by fiscal year for Composite Materials Laboratory ($ in millions)

	1991	1992	1993	1994	1995	1996
Operating	8.5	9.5	11.0	12.5	14.5	16.0
Capital	1.0	0.3	0.2	0.5	1.0	0.4
Total	9.5	9.8	11.2	13.0	15.5	16.4

community of guests and users (Fig. 17). The OGUI facilitates guest and user access to collaborative research facilities at ORNL by disseminating information about designated user facilities; identifying user facility and other opportunities for collaborative research; providing assistance with the access and approval procedures that visits to ORNL require; negotiating legal agreements on research interactions; and assisting visitors with housing, transportation, etc. The OGUI supports 13 ORNL user facilities that have become important components of the DOE/ORNL mission. The user facilities satisfy national R&D needs, broaden the ORNL research base, and leverage the available funding. The OGUI handles more than 2300 visits annually by scientists and engineers from universities, industries, and other federal laboratories. Despite its growing importance, the OGUI is currently housed in temporary trailers. The MS&E Complex is a logical site for construction of a permanent OGUI because the majority of ORNL user interactions are materials related. An FY 1992 GPP building of about 3200 ft^2 (to be constructed at a cost of about $1.2 million) is proposed as a permanent OGUI.

High-Energy Physics Research and the Oak Ridge Detector Center

Successful use of the SSC for high-energy physics investigations will require design and construction of a new generation of detector systems in parallel with the design and construction of the SSC. Preliminary R&D has been initiated for this purpose through both DOE and the SSC project. Each detector system will be a major development task that will cost several hundred million dollars. The task will not only involve targeting particular areas of high-energy physics and planning an associated research program, but it will also require a broad multidisciplinary approach to solve the various materials, engineering, data acquisition and analysis, and physics problems associated with the detector. Close coordination among the ORNL science programs and Energy Systems central engineering organization will be required.

Fig. 17. Conceptual drawing of the Office of Guests and User Interactions.

During the past several years, southern universities and ORNL have held many meetings concerning the development and expansion of high-energy physics in our region. These meetings were driven in part by the SSC project and by a true desire to play a large role in the new physics to be provided by that accelerator facility. Out of these meetings emerged the Southern Association of High Energy Physics (SAHEP). SAHEP is now charted under ORAU and has a membership exceeding 15 universities and other organizations including ORNL. In addition, close ties are maintained with SURA. The SAHEP organization acknowledged the strategic location and facilities of ORNL and recognized the importance of having ORNL play one of the focusing roles in the region.

During the past year, ORNL has been approached by the L-Star and Solenoidal Detector collaborations (which include SAHEP members) to provide them a detector component development base. At present, the majority of the L-Star collaboration and development personnel are located in Europe, but this must eventually switch to locations in this country because most of the final detector design and construction will be done here. The prime responsibilities that we have assumed for the L-Star collaboration deal with the calorimetry part of the detector and with the system integration of the entire detector. The prime responsibility that we have assumed for the Solenoidal Detector Collaboration deals with the engineering and design of the central tracking chamber. To respond to these needs and demands on the facilities of ORNL, the Laboratory has established the Oak Ridge Detector Center (ORDC).

The purpose of the ORDC is to serve as the focal point for all science and engineering divisions involved in SSC-related research and to provide an organizational interface with outside collaborators in the area of SSC detector R&D. The goals of the center will be: (1) to establish the southeast as a major force in high-energy physics; (2) to enhance cooperation for joint detector R&D between ORNL, universities, and private industries; (3) to build a technology base for the engineering, designing, constructing, and testing of major components of SSC-style detectors (Fig. 18); and (4) to conduct detector R&D for other physics programs such as the Relativistic Heavy Ion Collider and the ANS.

Currently, several collaborations have been established among the universities in SAHEP, other high-energy physics institutions around the country, and ORDC. These collaborations include

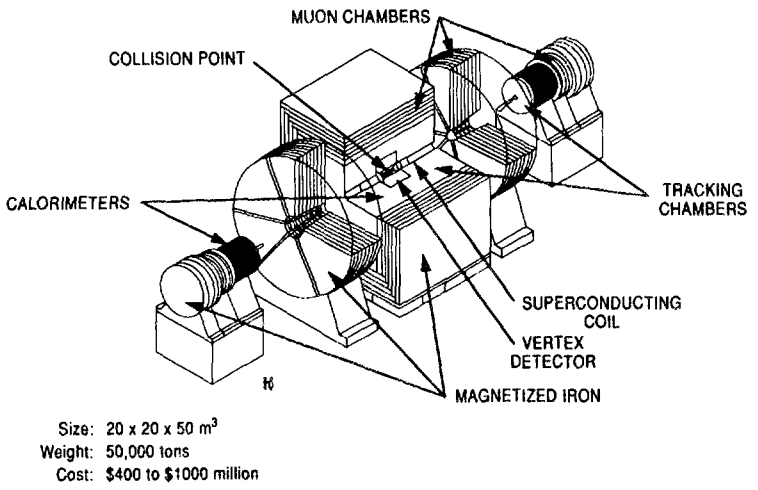


Fig. 18. ORNL will be involved in designing, engineering, and building detector components for the SSC.

research in areas such as detector simulation; radiation damage; and electrical, mechanical, and materials engineering. The funding for these research projects is currently coming from the DOE/SSC Laboratory and is anticipated to increase during the next several years.

In the future, it is hoped that out of these collaborations joint appointments will evolve between ORNL/ORDC and the SAHEP universities that are similar to the current joint appointments now existing between UTK and ORNL.

In parallel with the work of the ORDC, a major expansion of the existing ORNL/UTK high-energy physics group will be undertaken. The expansion of this group will include both experimental and theoretical physicists, in most cases appointed jointly at both institutions. In addition to providing a technical interface with the national and international high-energy community, this group will provide additional expertise in matching detector R&D to experimental requirements and in providing a continuing involvement of the Laboratory in the data-taking and data-analysis phase of the SSC program. As part of this initiative, the Laboratory has joined the L3 collaboration at Conseil Européen pour Recherche Nucléaire and is now represented on the steering committee for the L-Star collaboration preparing a major detector proposal for the SSC.

The nature and extent of our involvement in the SSC are still evolving as the SSC project gains momentum nationally. ORNL will continue to explore and define the appropriate role of the Laboratory in this important national initiative. Because of ORNL's diverse multidisciplinary research program, the Laboratory is well positioned to make major contributions to numerous aspects of the SSC project and the high-energy physics research program to follow. The magnitude of the anticipated growth is indicated by the projected new funding (Table 16).

High-Temperature Superconductor Research and Development

Recent discoveries of new superconducting materials with high critical temperatures have generated interest in the scientific community and offer the widespread potential for significant applications in numerous energy technologies. However, a great deal of basic research and applied materials development will be required before these new materials are understood and developed to meet future applications requirements. The primary goals of ORNL in this exciting field are to carry out a coordinated R&D effort to understand the new high-critical-temperature superconducting oxides, to develop the fabrication technologies for conductors with high-critical currents in the presence of high fields, to identify viable commercial applications, and to work closely with U.S. industries to accelerate the commercial application of these discoveries. The R&D efforts focus on four major areas: (1) synthesis, (2) characterization and analysis,

Table 16. Budget projections by fiscal year for High-Energy Physics Research and the Oak Ridge Detector Center ($ in millions)

	1989	1990	1991	1992	1993	1994	1995	1996
Operating	0.3	0.3	0.9	1.5	2	2	2	2
Capital	0.04	0.2	0.4	1.5	2	2	2	2

(3) thin films and devices, and (4) high-current conductors.

Our basic research program in these new materials was initiated in FY 1988 with redirected funds totaling about $1.8 million. In FY 1988 and 1989 this research grew to about $4.5 million, with new and additional redirected funds to support this research initiative. ORNL also established close research interactions with Los Alamos National Laboratory (LANL) and Lawrence Berkeley Laboratory.

Applied R&D programs for conductor and application development were initiated in FY 1988 with about $0.5 million funding from the Office of Energy Storage and Distribution and the Division of Energy Conversion and Utilization, Conservation, and Renewable Energy. This effort has increased to about $1.1 million in FY 1990 and is expected to increase to $5 million by FY 1994 as the technology for practical conductors and applications is developed.

During FY 1988, ORNL was named one of three DOE Superconductivity Pilot Centers. The other two pilot centers are at LANL and Argonne National Laboratory. The purpose of these pilot centers is to promote increased interactions between the national laboratories and U.S. industries on high-temperature superconductor materials and applications to accelerate the transfer of this technology to the private sector. This program has provided increased flexibility and streamlining of business and legal interface between DOE and U.S. industries to enable cooperative R&D on the technology development and applications of these materials, which will accelerate commercialization. FY 1990 funding for the SPC program was $1.8 million and is scheduled for an increase to $5 million in FY 1991, based on the tremendous response of U.S. industries for participation in this program (Table 17).

ORNL Facilities Restoration Program

The capital plant facilities at ORNL have served for many years in support of productive research programs at ORNL. However, because of insufficient capital improvement funding for modernization and adaptation to changing program needs over ORNL's 40-plus year history, many of the Laboratory's buildings and utility systems have deteriorated to substandard conditions. Deterioration has been especially damaging in buildings that were constructed very quickly for temporary use as part of the World War II Manhattan Project.

Table 17. Budget projections by fiscal year for R&D and the High-Temperature Superconductor Pilot Center (includes both new and redirected funds; $ in millions)

	1989	1990	1991	1992	1993	1994	1995	1996
Basic Research (ER)	4.5	4.5	5.0	5.0	5.0	5.0	5.0	5.0
Applied R&D (CE)	0.8	1.1	1.5	2.5	4.0	5.0	5.0	5.0
Superconductivity Pilot Center[a] (CE)	1.5	1.8	5.0	5.0	5.0	5.0	5.0	5.0
Total High-Temperature Superconductor R&D	6.8	7.4	11.5	12.5	14.0	15.0	15.0	15.0

[a]Pilot Center funds do not include industrial cost/share.

While ORNL research programs still continue to produce some of the finest results in energy development and science projects anywhere in the world, the impact of continuing deterioration of facilities is taking a significant toll. Some examples of these effects include the fact that operational overhead rates have had to increase nearly 50% over the last several years in order to comply with current environmental, safety, and health regulations governing our facilities and their operations; thus, research program funding and, therefore, productivity have been reduced. Also, certain office areas have had to be vacated because of failure to meet OSHA requirements. This situation combined with a funding-limited ability to convert radiation-contaminated areas to productive office and clean laboratory space along with a significant increase in the number of on-site guests, has contributed to a severe overcrowding problem. The combined overcrowding and substandard work spaces in many buildings creates a major negative impact on our ability to attract the highest quality staff to the Laboratory.

Surveys of building and utility system conditions show that 45% of the total building space is in need of renovation or replacement, including World War II vintage wood-frame and Quonset-type structures currently used for both office space and laboratories. Many basic systems such as roofs; electrical distribution; piping; and heating, ventilating, and air conditioning have greatly exceeded their designed life expectancy and do not properly meet the needs of current research programs.

To meet these facility improvement challenges, ORNL has established this major new initiative. We view this initiative to include work that has already begun in a limited way with previously approved, line-item, upgrade projects in areas such as piping systems, electrical distribution, fire protection, and road safety improvements as funded by DOE's MEL-FS Program. However, much more needs to be done. Continued renovation or replacement work is required in the following general categories:

Facilities	Funding requirements ($ in millions—FY 1990)
Replacement of obsolete buildings (including demolition of old structures)	155
Building renovations	22
Roof replacements	10
HVAC upgrades	51
Central steam plant replacement	50
Electrical system upgrades	20
Piping upgrades	59
Sewage system improvements	10
Maintenance shops and equipment replacements	43
Parking and grounds improvements	5
Miscellaneous	25
Total	450

It is anticipated that this initiative would be continued in a significantly expanded effort throughout the planning period and into the 2000-year time period. It should also be noted that other special requests currently being prepared for OSHA compliance and environmental restoration are not included as part of this initiative.

The following are specific line-item requests supporting this initiative, and budget projections are given in Table 18.

Project No.	Title	Total estimated cost ($ in millions)
	FY 1992 budget submission	
92-KG01-2	Upgrade steam distribution system, west end	9.0

	FY 1993	
93-KG01-1	Central research support building	12.1
93-KG01-3	Reroofing	15.0
93-KG01-6	Maintenance support and decontamination laundry building	16.0
93-KG01-7	Sanitary sewerage system	11.0
93-KG01-8	Upgrade building HVAC systems, phase I	15.0
	FY 1994	
94-KG-	Restoration of potable water system	12.0
	Restoration of fire water system	5.0
	Refurbish building exteriors, ORNL at Y-12	7.5
	Replace oil-filled transformers	4.3
	FY 1995 and beyond	
KG01	Restoration of Central Research Complex	60.0
	Upgrade building HVAC systems, phase II	25.0
	Restoration of electrical substations, switchgear, and distribution system	18.0
	Upgrade coal yard runoff treatment facilities	2.0
	Steam plant emissions improvements	15.0
	Safeguards and security building	15.0
	Refurbish metallurgical hot cells	50.0

Other Initiatives

Additional initiatives are proposed under program discussions in the section "Scientific and Technical Programs."

Office of Energy Research

Advanced Photonics for Environmental Needs

This initiative, which is interdisciplinary and interdivisional, is designed to coordinate novel instrumentation developed in ORNL's Health and Safety Research Division with the needs of environmental scientists and ES&H specialists.

The Liquid State of Matter

This initiative will focus on achieving understanding of fundamental liquid-phase behavior with the goal of predicting new phenomena and improving existing technologies.

Subsurface Research

Research will be directed toward understanding and predicting contaminant migration in the subsurface in response to DOE's waste R&D plans.

Table 18. Budget projections by fiscal year for the ORNL Facilities Restoration Program ($ in millions)

	1991	1992	1993	1994	1995	1996	1997	1998	1999
Operating	1	5	9	0	0	0	0	0	0
Capital	6.5	1.1	21.5	50	50	100	100	50	50

Environmental Biotechnology

This interdisciplinary initiative will focus on developing new systems that degrade or stabilize contaminants into nonhazardous forms.

Genome Mapping and Sequencing

Experimental molecular genetics is used to explore structural and functional characteristics of the mammalian genome.

Structural Biology

The purpose of this initiative is to develop biological applications of small-angle neutron and X-ray scattering and neutron and X-ray crystallography.

Human Health Risk Analysis

This initiative will assist DOE and other federal agencies to ensure that resources being expended for environmental restoration are used effectively to provide human health protection.

Assistant Secretary for Nuclear Energy

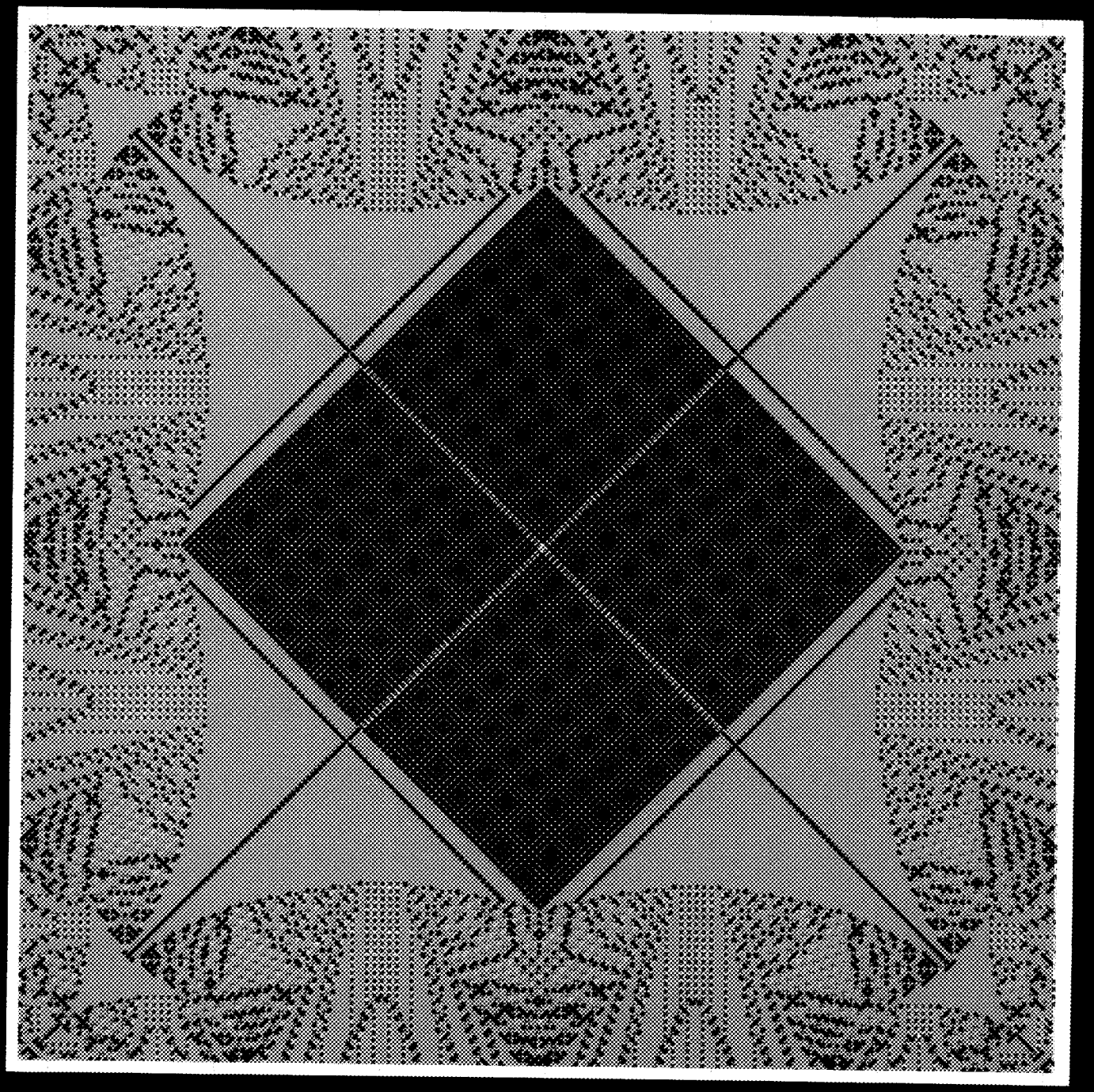
Actinide Burning

DOE is undertaking a reexamination of actinide burning in which actinides are recovered from spent nuclear fuel and used as fuel in fast reactors where they are ultimately fissioned. The purpose is to reduce the long-term hazards in a geologic repository.

Nuclear Propulsion for Space Exploration Initiative

ORNL can contribute to the development of nuclear propulsion technology needed for the Space Exploration Initiative, which is aimed at colonization of the moon and a manned expedition to Mars.

Scientific and Technical Programs



Scientific and Technical Programs

Department of Energy

Office of Energy Research

The Office of Energy Research is the largest single sponsor of research at ORNL. It supports ORNL's major research programs in the basic physical sciences, fusion energy, and biomedical and environmental sciences (Table 19).

AT—Magnetic Fusion

The Fusion Energy Program at ORNL is a major component of DOE's Magnetic Fusion Program. Two characteristics distinguish ORNL in this activity: (1) the extensive collaboration both nationally (with numerous universities, industries, and national laboratories) and internationally (with ten countries) and (2) the breadth of the component subprograms in physics, technology, and systems studies. Work is carried out in several

Table 19. Office of Energy Research major program summary
[$ in millions—budget authorization (BA)[a]]

Budget and reporting code	Major program	Fiscal year			
		1989	1990	1991	1992
AT	Magnetic Fusion	39.1	29.9	29.7	30.0
AT	Landlord activities[b]	9.7	9.0	122.9	130.7
KA	High-Energy Physics	0.8	0.4	0.4	1.1
KB	Nuclear Physics	14.8	15.3	14.8	18.0
KC	Basic Energy Sciences	77.8	77.3	79.3	95.9
KD	Energy Research and Analysis	1.5	2.1	1.0	1.5
KE/KT	University and Science Education	0.8	0.8	0.4	0.6
KG (EX)	Multiprogram Energy Laboratories Facilities Support	28.8	31.3	31.4	22.4
KP	Biological and Environmental Research	26.3	27.7	27.1	29.2
KS	Superconducting Super Collider		0.7	0.2	0.2
Total		199.6	194.9	307.2[c]	329.6[c]
Percentage of total Laboratory funding—BA		41.8	38.2	45.6	45.3

[a]Includes funded operating BA, capital equipment, and construction as noted in Table A.5 in the Appendix.

[b]Includes general plant equipment (GPE) and general plant project (GPP) funding and two field-work proposals for the Occupational Safety and Health Administration (OSHA) and other safety activities.

[c]Includes field work proposals for OSHA and other health and safety compliance.

ORNL divisions, and major contributions are made by the Engineering, Computing and Telecommunications, and the Oak Ridge Y-12 Plant organizations. The goal of the Magnetic Fusion Program is to determine whether useful energy can be obtained from the fusion of light elements, mainly the isotopes of hydrogen (deuterium and tritium).

The physics goal is ambitious because very high temperatures are required (1×10^8 K or more). The purpose is to confine the very hot hydrogen gas (a plasma) using magnetic fields. Principal characteristics of such plasmas are the plasma thermal conductivity (a measure of the insulation of the hot plasma from its surroundings) and the quantity "beta" (the ratio of plasma pressure to magnetic pressure). To produce an ignited plasma, the insulation must be sufficient to allow energy confinement times of several seconds at plasma densities of $10^{20}/m^3$. Beta values of about 10% are believed to be necessary for fusion to be economically viable.

Magnetic fusion also sets many demanding technology goals for high-field superconducting magnets, heating and fueling systems, materials, lithium blankets to breed tritium, and remote-handling techniques. These components must withstand the fusion environment of 14-MeV neutrons.

The achievement of these goals is important for the world because fusion is an essentially unlimited source of energy, which also has the potential for a substantially reduced environmental impact compared with other energy sources.

Support for the ORNL program comes from three subprograms: Applied Plasma Physics (AT05), which funds theory, atomic physics, and diagnostic development; Confinement Systems (AT10), which funds confinement experiments, the Compact Ignition Tokamak (CIT), and some applied plasma technology; and Development and Technology (AT15), which funds materials research, plasma technology, International Thermonuclear Experimental Reactor (ITER), and systems studies.

AT05—Applied Plasma Physics The Applied Plasma Physics subprogram at ORNL includes theoretical and computational studies to formulate, validate, and apply theoretical models of plasma behavior to toroidal confinement systems. The primary emphasis is on understanding plasma confinement and its limitations in both tokamaks and stellarators. The essential similarities of the two concepts simplify analysis, while the differences can be exploited to isolate specific physical phenomena. The most notable differences are instabilities driven by currents parallel to the magnetic field. ORNL contributions include work in the following areas:

- transport driven by instabilities, as assessed by ORNL stability models;
- effects of turbulent- and dc-electric fields;
- tailoring of magnetic fields to reduce particle drift losses and lower collisional transport;
- fueling and heating techniques to adjust profiles and to control energy and particle losses; and
- dc-current drive [radio frequency (rf) beams] for tokamaks.

The theoretical effort is directed toward applications that improve U.S. tokamak initiatives (CIT, ITER, and the Advanced Reactor Innovation and Evaluation Study). Major collaboration will continue on theoretical studies with the world stellarator program to develop key future experiments in Japan, Europe, and the U.S.S.R. Studies of an advanced toroidal facility (ATF-II) to test the physics of an attractive toroidal reactor will also continue.

Low-aspect-ratio tokamak ideas developed at ORNL have led to plans for experimental tests of such devices at several sites, and for collaborations, most notably at the Culham Laboratory in England; the Instituto De Pesquisas Espacias in Brazil; and the A. F. Ioffe Physico-Technical Institute in the U.S.S.R.

The development of data bases and theoretical models for atomic physics and fusion plasma diagnostics has been undertaken in the Physics Division. Within the past several years, a powerful new source of multiply charged ions has contributed 90% of the available ionization cross-sectional data base for fusion-relevant ions and should continue to support fruitful research for many years. In a separate program, a very

promising laser-based diagnostic for fusion alpha particles is installed on the ATF and will begin proof-of-principle tests soon.

AT10—Confinement Systems The main focus of the Confinement Systems subprogram at ORNL is the ATF experiment, which started operating in 1988. The ATF has the flexibility to study various magnetic configurations and to contribute to the understanding of toroidal confinement. Measured values of the plasma-driven (bootstrap) current are in agreement with theory (Fig. 19). Plasma fluctuations measured in the plasma edge using a probe provided by the University of Texas are sufficient to explain the plasma losses and are similar to fluctuations in tokamaks. The ATF has already accessed the second stable region of operation, which promises improved performance for tokamaks and stellarators. The ATF will also allow the study of electric-field effects on plasma transport. The ATF coils can achieve steady-state operation, which will enable the ATF to be used to investigate steady-state physics and technology problems in the future.

The first phase of ATF operation has been completed successfully. Plasmas have been created using electron-cyclotron heating and neutral beams with densities up to $10^{20}/m^3$, a central electron temperature up to 1.3 keV, a volume-averaged beta up to 1.6%, and an energy confinement time of 25 ms. Central betas up to 3.0% have been achieved with 1 MW of neutral-injection heating. Improved diagnostics, a pellet injector, and increased heating power should improve all these parameters in 1991.

The Confinement Systems subprogram also sponsors work on techniques for understanding and controlling the plasma boundary. This work includes pumped limiters and divertors, which remove particles from the edge of the plasma. This activity will continue its strong collaboration in the pumped limiter programs on the Tokamak Experiment for Technical Oriented Research (TEXTOR) (Germany) and Tore Supra (France). In TEXTOR, helium removal with a pump limiter has been demonstrated (Fig. 20). In addition, a similar major program using the ATF will be undertaken on limiters, divertors, edge-plasma diagnostics, and surface physics. Activities involving collaboration on divertors, heating, and diagnostics are progressing well with the Doublet III-D group (General Atomics) and the Texas

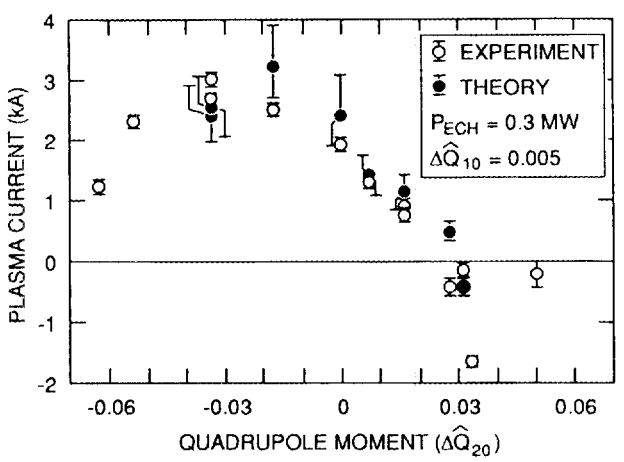


Fig. 19. The values of bootstrap current agree with the theoretical predictions.

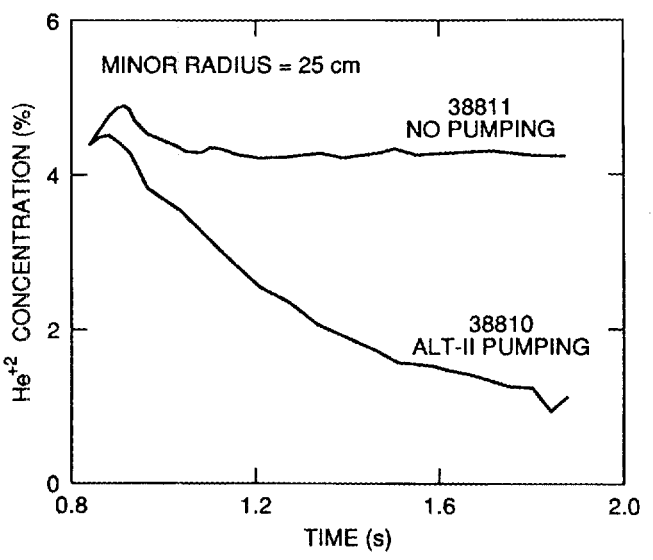


Fig. 20. Successful removal of helium from TEXTOR using a pump limiter [Julich (Germany), UCLA, Nagoya, ORNL, the Princeton Plasma Physics Laboratory, and Sandia]. A short helium gas puff (20 ms) is injected at time = 0.75 s into a neutral beam heated discharge, producing a central helium concentration of about 5%.

Experimental Tokamak group (University of Texas at Austin).

AT15—Development and Technology

The Development and Technology subprogram at ORNL continues to make impressive contributions throughout the breadth of its work. ORNL is a major center for the development of heating systems for plasmas. In recent years, this work has been directed at developing systems for heating with electromagnetic waves, commonly referred to as rf systems. The ORNL Radio Frequency Test Facility is an important element in the development and test of the rf launching structures. An ion-cyclotron current-drive heating system has been built for the Doublet III-D (Fig. 21). ORNL has also provided ion cyclotron heating launchers for the Tokamak Fusion Test Reactor at the Princeton Plasma Physics Laboratory and the Tore Supra Tokamak in France. ORNL scientists will participate in rf heating experiments on these machines. ORNL is also responsible for the CIT rf heating system.

The principal method of fueling plasmas is by the injection of pellets of solid hydrogen at high speed (>2000 m/s). The pellet injector program continues to be one of ORNL's outstanding contributions to the advancement of the world fusion program. A system has also been supplied to the Tokamak Fusion Test Reactor and to the Joint European Torus, a project of the European Economic Community. An injector has been installed on Tore Supra and initial injection experiments have been successful.

Concepts are being tested for producing significantly higher-velocity pellets. Two-stage, light-gas guns are being developed for application on current experiments as well as CIT and ITER. Speeds of up to 4500 m/s have been achieved with room-temperature pellets while unprotected cryogenic (hydrogen) pellets have been accelerated to about 3000 m/s. Recently, a two-stage gun has, for the first time, operated in a repeating mode. Also, an innovative concept with the potential of >10,000 m/s (using electron beams to create a rocket effect at the back of the pellet) is also under early stages of development (Fig. 22).

It takes many years to develop a production capability for radically new materials, and in anticipation of fusion's needs, such development has been under way at ORNL since the 1970s. Substantial advances have been made in the development of alloys to withstand the fusion neutron environment. A major thrust of the program is to concentrate on alloys that will have low induced radioactivity. Promising austenitic and ferritic steel compositions with favorable mechanical properties have been produced. Work

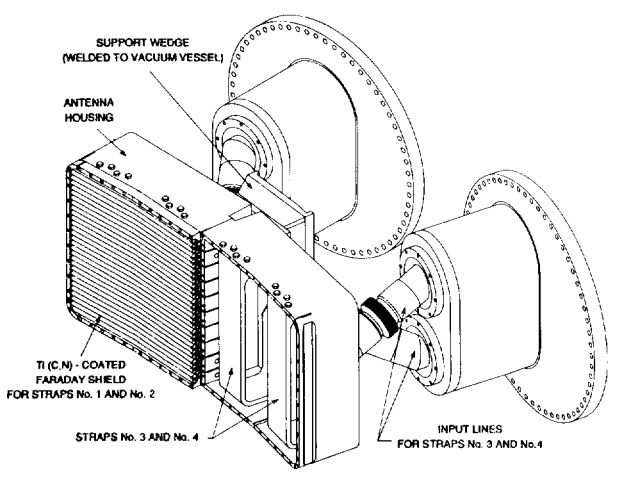


Fig. 21. Schematic drawing of a fast-wave current-drive antenna for the Doublet III-D (General Atomics) (30–60 MHz, 2 MW, 2 s, 4 straps with arbitrary phasing).

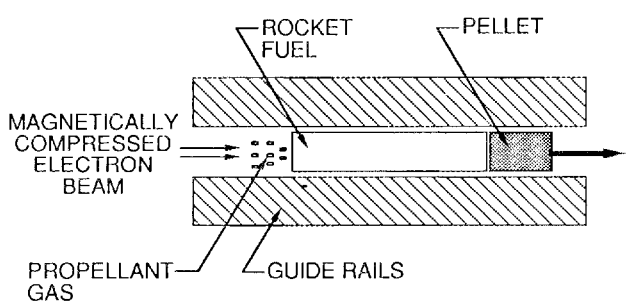


Fig. 22. Electron-beam rocket pellet accelerator concept.

is also under way to resolve key material problems for CIT and ITER. These alloys are being tested in the High Flux Isotope Reactor (HFIR) irradiation facility. Other irradiation experiments involving graphite and carbon-based ceramics are also under way. A multiyear collaboration with the Japan Atomic Energy Research Institute is a key part of this program.

The Advanced Systems Program has been organized as a focal point for activities related to future fusion experiments. The ORNL Fusion Engineering Design Center (FEDC) is the major engineering resource for the program. Since its formation in 1979, the FEDC has played a leading role in the design of next-generation devices. The FEDC has collaborated extensively with U.S. industries, national laboratories, and universities. ORNL and the FEDC play a major role in the design aspects of ITER with contributions in physics, reactor design and integration, remote handling, and plasma technology systems. The FEDC also contributes to the Advanced Reactor Innovation and Evaluation Study headed by the University of California at Los Angeles.

ORNL is also applying its fusion technology expertise to a variety of nonfusion applications. Examples include the use of microwaves to sinter ceramics and process liquid wastes, microwave plasmas for the production of semiconductors, plasma processing for cleaning and preparing surfaces, production of diamond coatings, and the application of magnetic expertise to advanced superconducting magnets for a variety of defense and civilian needs.

The following are longer-term (3- to 15-year) goals of the ORNL Fusion Program:

- to play a major role in the U.S. initiative to improve the understanding of toroidal confinement. Key elements of the contributions will be further comparison of ATF characteristics with those of similar-scale tokamaks and stellarators and coupled theory, plasma modeling studies, and diagnostic and plasma technology development;
- to study high-beta, high-temperature, long-pulse to steady-state plasmas in ATF and use ATF as a test bed for plasma technology;
- to develop and build ATF-II—an advanced toroidal device, based on ATF and the world tokamak and stellarator programs, that will have a reactor-grade plasma—on a new site in Oak Ridge;
- to support spherical torus research in the world program;
- to continue a broad technology program with emphasis on heating, current drive, fueling, and materials;
- to give special emphasis to the remote-handling needs for CIT and ITER;
- to perform major engineering and technology application roles in support of the CIT;
- to develop a similar role in the ITER program, including the development of materials, remote handling, plasma heating, fueling, and current-drive systems; and
- to maintain a strong position for Oak Ridge to be the site for major deuterium-tritium burning plasma facilities in the future.

Steady-State Operation of the ATF

The ORNL ATF is the world's largest stellarator fusion experiment. The base device cost is about $100 million. It was designed as a flexible research facility to complement the mainline tokamak in developing an understanding of toroidal magnetic confinement physics. Since start of operation in 1988, the ATF has already made significant contributions to this understanding. In addition, a stellerator (in particular the ATF) has the potential for steady-state operation without dangerous disruptions or the need to drive large plasma currents, which are potential limitations to a tokamak fusion reactor. The benefits of steady-state operation in the ATF to the U.S. fusion

program would be twofold: (1) demonstration that a toroidal plasma device is capable of steady-state operation at high edge power densities and with efficient use of the magnetic field (high beta) without plasma deterioration because of plasma-wall interactions or disruptions; and (2) use of ATF to test plasma-facing components and materials for high-power flux, steady-state operation in fusion experiments.

Although designed for high-power (6–8 MW) steady-state operation, the ATF has been limited to moderate power (2 MW) short-pulse (0.3 s) operation because of inadequate resources for the necessary plasma heating and fueling systems and the particle and heat removal systems. Present funding allows for a doubling of the short-pulse plasma heating and determination of the design criteria for steady-state operation, but not implementation of the steady-state additions. Incremental funding is needed for vacuum vessel cooling and divertor modules, cooling of power supplies and buswork, steady-state pellet injection and pumping, and construction of high-power steady-state plasma heating systems (Table 20).

Table 20. ATF steady-state resource requirements
($ in millions)

	Fiscal year					
	1991	1992	1993	1994	1995	1996
Operating	3.1	6.8	4.9	4.7	3.3	3.3
Equipment	0.7	1.2	0.9	2.2	8.0	8.0

The resulting ATF program would proceed in stages: (1) steady-state operation at low power (0.1 MW) and at reduced magnetic field in 1991; (2) moderate pulse length (5–20 s) at moderate power (~3 MW) at normal operating fields in 1992; (3) addition of full steady-state components in 1994; and (4) buildup of steady-state plasma heating capability from 2 MW in 1994 to 6–8 MW in 1997. This staging allows optimization through experience as the power and pulse length capability is increased.

Environment, Safety, and Health Regulatory Compliance Upgrade The recent major increase in emphasis within DOE on full compliance with all aspects of environment, safety, and health laws; regulations; and orders has led to a comparable increase in the planning effort at ORNL to achieve improvements in the level of compliance throughout the facility. It was clear from the beginning of this effort that the resources required to remediate the legacy of noncompliances that has developed over many years, as facilities aged and requirements were tightened, and then to maintain the higher level of compliance would be well beyond the capabilities of any one R&D program to accommodate. However, as the nominal "landlord" for ORNL within DOE, the Office of Fusion Energy was chosen as the object of the field work proposals that evolved from this activity. It is presumed that decisions will be made within DOE to identify the appropriate sources of funding for the required effort.

A key task in achieving the desired compliance upgrade is a comprehensive identification of the needed corrective actions. This was begun with a series of informal internal assessments of noncompliances and remediation

actions. These have since been supplemented by a series of much more formal and comprehensive self assessments carried out in preparation for a Tiger Team evaluation of ORNL in the fall of 1990 and numerous internal and external appraisals of various aspects of Laboratory operations. Aside from the Tiger Team appraisal per se, others have recently been performed by teams from DOE Headquarters, the DOE Oak Ridge Office, Martin Marietta Corporate Headquarters, Energy Systems Central Staff, and private subcontractors to ORNL. All of these appraisals identified ES&H and quality deficiencies in need of correction, and many of the weaknesses were noted by more than one review. Plans for corrective actions have been or are being developed for each of the reviews; these activities will be followed by a comprehensive tracking and trending system to ensure that all agreed-upon actions are carried out as expeditiously and cost-effectively as possible.

Many of the deficiencies identified by the various assessments will require changes in operating and maintenance practices, which will impose substantial continuing higher costs on all Laboratory activities, major investments in new facilities, and the restoration of existing ones. The capital requirements for major restoration and replacement of facilities to achieve ES&H compliance are included in the overall planning activity for ORNL. They are described and listed as part of the Site Development Plan and as a restoration initiative. (See the Site and Facilities section and ORNL Facilities Restoration Program initiative.) In addition, two field work proposals were developed and submitted for separate funding beginning in FY 1991 to cover the ongoing operating costs associated with coming into and maintaining compliance with the Occupational and Safety and Health Act (OSHA) and with other ES&H requirements. The identfied funding needs for these two activities in FY 1991 were $113.7 million and $96.1 million respectively. (There is currently no indication that the requested direct funding will be provided, at least for FY 1991.) In the absence of such direct funding, a portion of the required activity will be supported by overhead charges against R&D tasks, but practical limitations on such charges will impose a substantial stretch-out of the schedule for full compliance in all areas of need.

KA—High-Energy Physics

The High-Energy Physics Program is anticipated to grow significantly in the future as a result of activity related to the national Superconducting Super Collider (SSC) project. The program almost doubled in size from FY 1988 to FY 1989 and more than tripled from FY 1989 to in FY 1990. In addition to existing activity in radiation-shielding design, the new activity includes high-energy particle-nucleus collision modeling and a significant increase in effort associated with the joint experimental high-energy physics program between the University of Tennessee (UT) and ORNL. Assistance is also provided to the SSC project by temporary assignment of a superconducting magnet specialist to work at DOE headquarters. The current high-energy physics research and development activities are expected to grow as the result of collaborative research initiated through the recently established Oak Ridge Detector Center. A major increase in effort will be associated with ORNL participation on the L-Star detector proposal for the SSC and the addition of ORNL to the L3 collaboration at Conseil Européen pour Recherche Nucléaire (CERN).

KB—Nuclear Physics

The Nuclear Physics Program emphasizes operation of and experimental research at two major user facilities: the Holifield Heavy Ion Research Facility (HHIRF) and the Oak Ridge Electron Linear Accelerator (ORELA). Experimental programs at these two in-house accelerator facilities are complemented by theoretical investigations of fundamental nuclear processes and by both theoretical and experimental collaborations with nuclear scientists at other facilities in this country and abroad. Experiments

include measurements with particle beams ranging in mass from neutrons to uranium ions and ranging in energy from kiloelectron volts to gigaelectron volts. Funding is expected to be relatively stable over the reporting period, with some increases in the Nuclear Theory Program (KB03). Accelerator improvement and maintenance funds ($345,000) are expected in FY 1991 for a continuing upgrade of selected beam-transport facilities.

KB02—Heavy-Ion Physics Task The HHIRF tandem accelerator continues to improve in terminal voltage performance, beam quality, beam current, and range of ions available for experiments. In September 1988, the tandem was operated with beam at a world record 25.5 MV. In this same time period, a new technique was demonstrated for the sputter generation of group 1A atomic negative ions.

Several new or significantly improved detector systems are now in heavy use at the HHIRF. Research efforts in the next several years will be centered in the exploitation of these devices. One of the new devices is a multielement array of barium fluoride crystals that can be used independently or in coincidence with the spin spectrometer or broad-range magnetic spectrograph for high-multiplicity particle-gamma coincidence measurements. The newly completed close-packed array of Compton-suppressed germanium detectors has made possible higher resolution and more detailed studies of nuclear properties at high spin and temperature. The multiphase Heavy-Ion-Light-Ion logarithmic counter for detecting coincident reaction products over a wide range of particle masses, energies, and reaction angles is now in full operation. This device has demonstrated an excellent dynamic range for studies at the energies accessible by the HHIRF accelerators. Another major new addition will be the Recoil Mass Spectrometer, a $2.2-million device jointly sponsored by ORNL, Oak Ridge Associated Universities, Idaho National Engineering Laboratory, and a number of universities. This apparatus will be designed and assembled early in the planning period with initial operations planned for FY 1992.

ORNL staff members are heavily involved in development activities in support of the proposed Gammasphere facility, (see Initiatives section) estimated to cost about $17 million for capital equipment and up to an additional $3 million for site preparation and installation. The HHIRF has been recommended by a DOE review panel as the site for this device.

Computing facilities will continue to be upgraded with further implementation of Advanced Computer Project multimicroprocessor systems. Initially utilized for processing the volumes of magnetic data tapes generated in experiment WA80 at CERN, these systems will be applied to data from experiments using the large detector arrays at HHIRF and further developed as "front-end" processors for real-time data acquisition on these same detector systems and for the Gammasphere project.

Experimental efforts under this program will continue to emphasize nuclear spectroscopy and reaction studies at HHIRF. This program is expected to be dominated by Gammasphere-related research at the completion of that construction project. The study of collective nuclear motion using a variety of hadronic probes will continue at a number of accelerator facilities in the United States and abroad, as will the studies of ultrarelativistic heavy-ion collision processes at Brookhaven National Laboratory and at CERN.

KB03—Nuclear Theory Program Major thrusts of the Nuclear Theory Program are

- mean field (time-dependent Hartree-Fock) descriptions of low- and intermediate-energy heavy-ion collisions;
- studies of the manifestations of strong, pulsed electromagnetic fields in ultrarelativistic heavy-ion collisions;
- heavy-ion direct reactions near the Coulomb barrier;
- studies at the interface of nuclear and particle physics; and
- pion propagation in nuclear matter.

Holifield: the Makings of a World Research Center

The Holifield Heavy Ion Research Facility (Fig. 23), a landmark in the heavy-ion research field for nearly 10 years, is now evolving its capabilities to serve as the world center for nuclear-structure research.

The Holifield's strengths include an internationally heralded outside-user program, which involves hundreds of scientists from throughout the world; an array of unique instruments, some already in operation and others on the drawing board; the nation's largest and strongest nuclear-structure theory group, whose work both informs and builds on the experiments at the facility; and exceptionally strong support from the state of Tennessee and two Tennessee universities, which have provided funding, equipment, facilities, and staff to support the Holifield's programs.

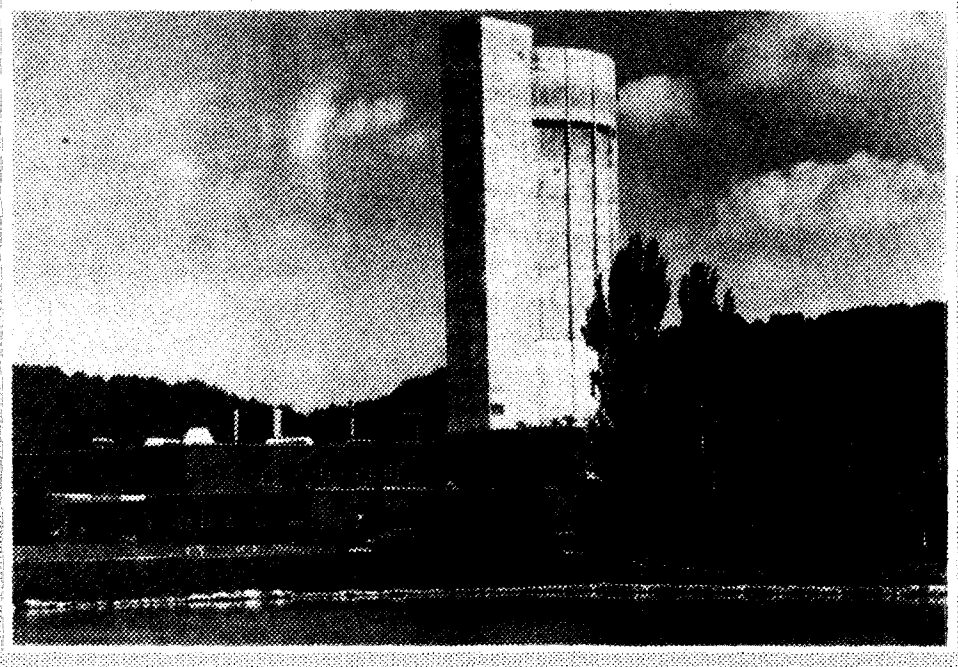


Fig. 23. The Holifield Heavy Ion Research Facility.

"HHIRF is the *world's* leader in user support. They have established a scientific climate where . . . all the experimental aspects are supported, where theoretical support is close at hand, where the human needs of the scientists are accommodated, where good exchange between different groups is encouraged and cultivated."

E. F. Zganjar
Louisiana State University

User Program In a comprehensive review in 1989, DOE's Gammasphere Siting Panel rated the Holifield's user program as "clearly . . . the best" among DOE's heavy-ion research facilities. Over the past 3 years, the Holifield has hosted more than 300 outside users from 87 institutions, including 49 U.S. universities, 19 foreign universities, and 13 foreign laboratories. User services at the Holifield include free lodging adjacent to the facility; a support group that helps maintain and set up experimental equipment; a mentor to offer guidance about each experimental device at the facility; and the Joint Institute for Heavy Ion Research, a unique collaborative endeavor of the state of Tennessee, ORNL, and the universities of Tennessee, offering a stimulating scientific environment through support of conferences and of guest scientists from throughout the world.

"Oak Ridge has been the most important laboratory in the whole world for training young Finnish nuclear physicists."

Jorman Hattula, Chairman
Finland Natural Science Research Council

Capabilities and Resources The heart of the Holifield facility is the 25-MV tandem electrostatic accelerator—with the Oak Ridge Isosynchronous cyclotron as an optional post-accelerator—which DOE's Gammasphere Siting Panel described as "a smooth-running facility" with the beam parameters needed for the Gammasphere. These machines currently offer the widest range of projectile species and energies of any heavy-ion facility in the world. An array of other specialized equipment, some existing and some planned, is designed to maximize the research range of the two accelerators.

The Oak Ridge University Isotope Separation (UNISOR) facility allows researchers to isolate and study exotic and short-lived radioactive nuclei. By chilling these highly unstable particles to near-absolute-zero (0.004 K), UNISOR renders them almost immobile, allowing slow-motion observation of their gamma-ray orientation and other properties that help reveal their nuclear structure. UNISOR is a collaborative program with Oak Ridge Associated Universities and 12 other universities.

The **Spin Spectrometer** is a 72-detector instrument for measuring the spin, or angular momentum, of the highly excited nuclei produced by heavy-ion collisions. These rapidly spinning nuclei give off energy in bursts of gamma rays, slowing and calming as they do. By capturing all or most of the gamma rays emitted, the Spin Spectrometer can take a far more detailed picture of the properties and behavior of the nuclei than instruments with fewer detectors.

The **Close-Packed Germanium Ball** is a smaller-scale precursor to the planned Gammasphere. The instrument's 20 germanium detectors, each surrounded by bismuth-germanate detectors to veto out incomplete events, represent the state-of-the-art in high-resolution gamma-ray spectrometers. It allows researchers to study, with high precision, the properties of discrete states in nuclei containing both large amounts of energy and large angular momentum.

"During the history-making studies of the Supernova 1987a, our group made pioneering measurements of the gamma-ray spectrum . . . The design of the instrument was based on our earlier experience in nuclear spectroscopy in Oak Ridge."

A. C. Rester, Director
Institute for Astrophysics and Planetary Exploration

The **Gammasphere,** which a review panel constituted by DOE strongly recommended be sited in Oak Ridge, is already a central focus of Holified planning and staff activities. The Gammasphere's 110 germanium detector modules will advance the sensitivity of gamma-ray spectroscopy by three orders of magnitude; the new instrument will be "the centerpiece of nuclear structure research well into the 21st century," according to the Gammasphere Siting Panel. The facility adaptations needed for the Gammasphere are already planned and can be readily accomplished. Our planned timetable will allow the instrument to begin experimental operation with a 60-detector array during 1992 and to achieve full-performance research with all 110 detectors in 1993. Oak Ridge's strong commitment to the project, clearly noted by the Siting Panel, will ensure a strong scientific return on this crucial research investment.

The **Recoil Mass Spectrometer** (RMS) represents the next generation in devices for selecting nuclei of a single species from among the billions of nuclei produced in heavy-ion-induced reactions. This unprecedented selectivity will enable researchers to explore radioisotopes that have never before been attainable. The RMS, which is a collaborative project with ORAU, INEL, and several universities, is scheduled for completion in 1992. Coupled with the Gammasphere, the RMS will offer heavy-ion research capabilities that will be unmatched anywhere in the world for at least the next decade.

The Holifield Heavy Ion Research Facility has made seminal contributions to nuclear physics over the past decade. One key contribution is a wealth of data about the interplay of collective motion and individual particle motions in shaping nuclear behavior. Another contribution—one just now emerging—is a new understanding of unexpectedly high rates of heavy-ion fusion at energies well below the Coulomb barrier—apparently through the formation of a "neck" of linking neutrons, which allows nuclear material to begin flowing between the two fusing nuclei. Still another contribution is the generation of physicists whose graduate and post-doctoral research at the Holifield will yield valuable scientific insights for many years to come.

Through the current and planned improvements to the Holifield's equipment and supporting capabilities—including an unsurpassed user program and strong links with many universities, research institutions, and the state of Tennessee—fundamental nuclear-physics advances such as these will continue to emerge from Oak Ridge well into the next century.

"The Holifield . . . is a jewel in the crown of U.S. nuclear science."

Harry Gove, Professor
University of Rochester

With the addition of an ORNL-UTK Distinguished Scientist, a new initiative has been launched cooperatively with UT for the study of quark phenomena in heavy-ion collisions. Also in cooperation with UT, the establishment of a Center for Computationally Intensive Physics has been proposed that will request joint funding from the state of Tennessee and DOE. An ORNL/UT Collaborating Scientist Program is being established to support this and other joint efforts. The first appointment will be in support of this center. The center is also involved in collaborating with UT and Vanderbilt University in supporting the Intel Hypercube Project.

KB04—Low-Energy Nuclear Physics Program The Low-Energy Nuclear Physics Program supports several tasks, including operation and research at ORELA, a unique pulsed neutron source accelerator facility for measurements by flight-time spectrometry of neutron cross sections and related quantities over

the entire range of 0.001 eV to about 80 MeV. Funding is also provided for related activities, including the evaluation of neutron cross sections as well as nuclear model development. This program also supports a large effort in studying the simple modes of nuclear excitation evidenced through giant resonances. These latter studies make extensive use of the facilities at HHIRF and at the Grand Accélérateur National d'Ions Lourds (GANIL) in France.

Initiatives include replacement of the existing ORELA data-acquisition computer system and utilization of a barium fluoride photon multiplicity detector system for capture and fission cross-section measurements in the eV neutron energy range. In connection with the DOE program of research pertinent to environmental restoration and waste management, the nuclear data base for actinides will be reviewed and additional neutron measurements at ORELA will be planned as appropriate. The usefulness of neutron transmission cross-section measurements will be investigated as quantitative indicators of the presence of specific nuclides in intensely radioactive samples.

KC—Basic Energy Sciences

The Basic Energy Sciences Program supports a broad spectrum of research in the physical sciences. The two largest subprograms are Materials Sciences (KC02) and Chemical Sciences (KC03). Several key issues face these subprograms, including a decision on shutdown or restart of the Bulk Shielding Reactor (BSR), development of the Advanced Neutron Source (ANS) (see Initiatives section), revival of the HFIR-based neutron-scattering and irradiation programs, and increased efficiency and effectiveness in user interactions.

KC02—Materials Sciences The Materials Sciences Program supports fundamental materials R&D, including neutron scattering; superconductivity; ion-beam, laser, and plasma processing; synthesis and characterization of new materials; high-temperature materials; ceramic processing; and theoretical studies for advanced energy-related materials. The Materials Sciences Program also supports a number of user facilities, including the Surface Modification and Characterization Collaborative Research Center, the Shared Research Equipment Program, the National Center for Small-Angle Scattering Research, and the Neutron Scattering Facility at the HFIR. Several of the Laboratory's initiatives are in the materials sciences: the ANS; the Materials Science and Engineering Complex, which includes the Center for Advanced Microstructural Analysis and the Center for the Study of Advanced Materials; and High-Temperature Superconductor R&D. KC02 funding is expected to increase sharply during the preconceptual design phase of the ANS, although the core program is expected to experience only moderate growth during the reporting period.

Research on the structure of materials will emphasize theoretical studies of metals, alloys, and ceramics, using state-of-the-art quantum-mechanical calculations of physical properties. Studies will continue using synchrotron radiation as both a scattering and spectroscopic probe to examine crystalline and amorphous solids. Growth is envisioned in microstructural analysis with the use of high-resolution analytical electron microscopy, energy-dispersive X-ray spectroscopy, and atom-probe field-ion microscopy. These microscopy techniques will be used to obtain new information on processes that involve microstructural change, such as phase transformations, segregation, and deformation.

The radiation effects program develops mechanistic understanding of the processes by which ion and neutron irradiation alter physical and mechanical properties of metals and ceramics. The work is directed at designing radiation-resistant metals and ceramics. This program will use the triple-ion-irradiation facility for most of its ion bombardments. Funding is expected to increase in radiation effects to support research in accelerated neutron embrittlement of ferritic steels prompted by ORNL investigations of low-fluence embrittlement of the HFIR pressure vessel. A new initiative in this area is the use of ion beams to modify surface structure and properties of polymers.

The engineering materials program includes

- fundamental welding science;
- physical metallurgy and mechanical behavior of ordered intermetallics;
- fundamental descriptions and understanding of mechanisms resulting in increased fracture toughness and strength in ceramics; and
- the structure and properties of surfaces, interfaces, and thin films.

The chemistry of advanced inorganic materials is a significant research area in which control of composition, purity, and morphology is emphasized in chemical synthesis. Tailored inorganic and organometallic precursor compounds and polymers are being developed whose pyrolysis and/or photolysis leads to nonoxide ceramics in powder, thin film, or fibrous forms. The discovery of novel synthetic approaches to transition metal nitride whiskers has generated a more general interest in topochemically specific gas-solid reactions. Ion-implantation preparative techniques, photoacoustic spectroscopic characterization, and electrochemical behavior are being combined in fundamental studies of electrocatalysis by mixed-oxide overlayers on metals.

There is a dual focus in the area of nucleation, growth, and transport properties, the first being the development of an understanding of the nucleation and growth of precipitation processes of ceramic precursors. The second involves the development of reactors and reactions that will lead to the reproducible production of pure and mixed ceramic precursors. Because the transport properties of the species involved in these processes have theoretical and process importance, an effort is continuing for the measurement of diffusion coefficients and viscosities.

Oxide superconductors are being investigated in the program on thermodynamics and kinetics of energy-related materials. One principal effort is the determination of and chemical thermodynamic modeling of the oxygen nonstoichiometry of several of the superconductors. These studies are typically done over a wider range of parameters than those usually reported and provide information that is used by others for interpretation of characteristics such as crystal chemistry and electronic properties. Other efforts include determination of the conditions for stability of superconducting phases and the kinetics of synthesis processes. Such information is used by others; for example, it can be used to control manufacturing processes. Close cooperation with similar efforts at ORNL and elsewhere is maintained to enhance the impact of the program, and currency with the literature is maintained.

Understanding the relationships among molecular structure, processing conditions, and performance properties of modern organic polymeric materials poses a unique challenge to structural chemists. Techniques being applied include neutron and X-ray scattering from both semicrystalline fibers and largely amorphous polymers and model compounds, neutron spectroscopy, thermal analysis, scanning-tunneling and atomic-force microscopy, and molecular dynamics simulations. Used in combination, these are revealing often unexpected structural and dynamic features, particularly in the semirigid parts of polymer systems. This program benefits from the presence of an ORNL-UTK Distinguished Scientist.

The neutron-scattering program focuses on the structure and dynamics of condensed-matter systems. The active neutron-scattering users programs at the HFIR will receive a boost from regular operation of the reactor and will expand with operation. During the HFIR shutdown, a reduced experimental program was conducted at other laboratories, and a strong effort was made to upgrade instrumentation at the HFIR. New instruments installed at the HFIR include a high-resolution powder diffractometer and a triple-axis spectrometer. A request has been made for line-item funding of a project to provide a more extensive instrumentation upgrade starting in FY 1992 (Table 21). The project will increase the scientific value of the HFIR with new instrumentation designed for transfer to the ANS (see Initiatives) or designed to provide a neutron-scattering technology base to allow better instrumentation for the ANS. The following improvements will be considered for inclusion in

Table 21. Budget for HFIR instrumentation upgrade ($ in millions)

1992	1993	1994	1995
1.2	3.8	4.6	2.4

this project: (1) the replacement of two existing triple-axis spectrometers with redesigned instruments; (2) construction of an experimental station for Polarized Options Spin-Echo Instrumentation Development On-Line (POSEIDON); (3) installation of a thermal neutron guide; and (4) construction of an improved neutron-imaging system.

Another area expected to grow steadily is the development of advanced processing techniques and studies of new materials systems. The advanced processing programs at ORNL emphasize the development of new thin-film materials and processing technologies using state-of-the-art surface-modification and characterization techniques. Facilities are available for ion implantation; ion-beam deposition; laser-photochemical-vapor deposition; laser and microwave processing; solar-cell fabrication; plasma processing [glow discharge, rf, electron-cyclotron resonance (ECR)]; and microanalytical and electrical characterization. Active research areas in processing include

- fundamental studies of ion implantation in materials (buried insulating layers, MeV implantation, damage and annealing studies, dopant activation, and ion-beam mixing);
- ion-beam deposition of heterostructures and epitaxial films;
- laser processing of high-efficiency silicon solar cells;
- fundamental studies of laser-solid interactions and laser-deposited films;
- high-speed epitaxial growth using supersonic molecular beams;
- laser ablation deposition of high-temperature superconductors and other materials;
- development of microionic materials and thin-film batteries;
- development of ECR plasma processing for growth of new thin film materials; and
- development of microwave sintering for ceramic processing.

The research involves silicon- and germanium-based materials (including oxides and silicides), III-V and II-VI compounds, superconductors, optical materials, ceramics, and novel electronic materials such as diamond. The research is carried out in collaboration with more than 50 scientists from industries and universities, many of whom perform research at ORNL facilities, such as the accelerators and lasers at the Surface Modification and Characterization Collaborative Research Center.

The Isotopes Research Materials Laboratory is a unique national resource for R&D on materials-processing methods used to provide the international research community with stable and selected radioactive isotopes in useful forms. The Division of Materials Sciences has discontinued base funding, leaving the future of this activity uncertain.

A major thrust in the materials sciences at ORNL is high-temperature superconductor R&D (see Initiatives section).

KC03—Chemical Sciences The Chemical Sciences Program supports the HFIR; the Radiochemical Engineering Development Center (REDC); and programs in atomic physics, basic chemistry, and chemical engineering. In the atomic physics area, an ongoing Laboratory initiative is the construction of the Heavy Ion Storage Ring for Atomic Physics (HISTRAP) (see Initiatives), a unique facility that will be capable of providing intense, high-resolution, heavy-ion beams with particle energies ranging from a few electron volts per nucleon to tens of millions of electron volts per nucleon. Construction of the HISTRAP is proposed for FY 1992.

The atomic physics program at ORNL encompasses both experimental and theoretical investigations of a broad class of phenomena

occurring when multiply charged heavy ions interact with gases, solids, free and bound electrons, photons, and other ions. Within the atomic physics program, ORNL currently operates the EN Tandem Accelerator, a user facility that provides a wide variety of light ions and multiply charged heavy ions at energies up to several million electron volts per nucleon. Experiments requiring higher beam energies are conducted at the HHIRF. Experimental studies of cross sections for inelastic collisions of multicharged ions with neutral atoms and molecules are carried out at the lowest attainable energies and are currently conducted using the ORNL ECR ion source. These studies emphasize characterizing the energy and angular distribution of ejected electrons. It is also proposed to undertake a new program to study details of ion-surface interactions. The ECR source and the HHIRF provide beams for merged-beam experiments. The merged-beams apparatus and the techniques currently being developed are applicable to the study of ion-atom chemical reactions involving unstable or reactive atomic species. An accelerator improvement and maintenance request has been submitted for an improved electron target for the merged-beam experiment (Table 22).

Table 22. Budget for the electron target AIM ($ in thousands)

1992	1993	1994
370	405	190

The atomic theory group has been significantly enhanced by the addition of an ORNL-UTK Distinguished Scientist. Areas of emphasis during this period will include applications of numerical techniques to atomic physics in the areas of low-energy ion-atom scattering, strong-field atomic physics, and chemical physics. Other initiatives include relativistic and quantum electrodynamics effects in atoms and investigations of the Coulomb three- and four-body problems. The KC03 atomic physics program is also participating in the proposed Center for Computationally Intensive Physics described in the KB03 discussion.

Preparations for restart of the HFIR reactor were intense over the more than 3 years of shutdown. Neutrons from the HFIR are vital to many research projects in the Material Sciences, Chemical Sciences, Magnetic Fusion, and Biological Sciences programs at ORNL and for users and collaborators from many universities, national laboratories, and industries in the United States and abroad. One of the prime purposes of the HFIR is to make research quantities of ^{252}Cf and other transuranium isotopes. The HFIR is unique in that it offers a combination of high flux with a mixed thermal/fission neutron spectrum, low irradiation temperatures, and flux tailoring. The facility is invaluable for neutron scattering, isotope production, and material-damage studies related to the Magnetic Fusion Program and to the design of other advanced reactor concepts such as the ANS. Now that the HFIR has been restored to full-power operations, emphasis must be provided on maintaining excellence in reactor operations and on revival of the neutron-scattering and irradiation programs. The BSR was shut down by DOE Oak Ridge Office order in the spring of 1987 because of a generic concern that affected all ORNL reactors. The HFIR is operating again, but efforts are needed to determine the intended future for BSR.

The Transuranium Processing Plant and Thorium-Uranium Recycle Facility have been renamed the REDC. Transuranium-element isotopes produced at the REDC are used throughout the world for basic physics and chemistry studies of the transuranium elements. They are also used in R&D programs relating to environmental effects, biological effects, and waste isolation. Basic chemistry studies of the actinides and transactinides emphasize the elements (curium and beyond) that are uniquely produced at HFIR-REDC or from HFIR products. The goal is elucidation of the behavior of the 5f electrons that characterize these heaviest elements in the periodic table. Experimental approaches applied to

these elements and their compounds include structural studies at high pressure and temperatures; characterization of unusual oxidation states in high-temperature vapors, nonaqueous solutions, and organometallic complexes; magnetic behavior; and plans for the first photoelectron spectroscopic study of 5f ionization dynamics of a free actinide atom. State-of-the-art relativistic quantum mechanics calculations are carried out to complement experimental studies.

Part of the analytical chemistry program moved in FY 1989 to the recently built Organic Chemistry Mass Spectrometry Laboratory at the X-10 site. An Inorganic Chemistry Mass Spectrometry Laboratory is currently being constructed. Approximately $1 million in basic energy science funds will be spent for new equipment for these two laboratories. This new facility will provide opportunities for collaborative research not previously available when much of the operation was housed at the Y-12 site.

ORNL conducts fundamental research in analytical concepts and methodologies:

- the use of lasers in advancing spectrochemical analysis,
- resonance-ionization mass spectrometry,
- glow-discharge mass spectrometry,
- gas-phase ion chemistry using mass spectrometry,
- ion-trap techniques,
- positron spectroscopy, and
- heavy-ion-induced X-ray satellite emission.

A truly significant accomplishment has been the detection of very large molecules—up to 660K daltons—in an ion trap mass spectrometer via electrospray ionization.

A unique array of complementary experimental and modeling techniques is applied to study thermodynamics of interactions and reactions in highly nonideal aqueous solutions of electrolytes at high temperatures and pressures. The systems studied are selected for their fundamental significance and for their relevance to energy-related technologies, including steam generation; nuclear and chemical waste disposal; the extraction of heat and mineral resources; and hydrothermal geochemistry.

Research in surface science/heterogeneous catalysis gives special emphasis to questions of surface structure and reactions involving sulfur-containing species on clean metals and surface alloys that serve as models for commercial hydrodesulfurization catalysts. The use of several ultrahigh-voltage surface-structure approaches (including low-energy ion scattering) and surface-reaction approaches is being expanded by incorporation of synchrotron-based approaches to characterize molecular adsorbates.

An area of continuing emphasis will be obtaining new molecular-level knowledge concerning the organic chemical structure and reactivity of coals. These studies highlight the application of solid-state nuclear magnetic resonance techniques to chemically modified coals and the use of surface-immobilized compounds to simulate diffusional restrictions during thermal processing of coal. The information derived from these fundamental studies will contribute to the development of novel processes for the use of coal as a source of liquid fuels and chemicals.

Research on the kinetics of enzyme-catalyzed processes will concentrate on the fundamental physico-chemical aspects of the conversion of light energy into chemical energy using artificial photosynthetic systems and the mechanisms associated with enzyme solubilization of cellulose and lignin. This research is in part directed at synthesizing a simplified photosystem capable of producing fuel from renewable resources. Another new initiative is an effort to pursue chemical means of improving the properties of the new high-critical-temperature superconducting materials. Also included in this effort is an investigation of synthetic deposition of gels to promote production of superconducting thin films.

Fundamental chemical and solid-state properties of the actinide metals and their compounds are being elucidated by a combination of experimental and theoretical tools. Particular emphasis is placed on changes in the behavior of the characteristic 5f electrons as one progresses towards the heaviest available elements. Structural

changes induced by high pressure and vaporization processes at high temperature are emphasized along with relativistic quantum calculations. Future plans include characterization of gas-phase actinide species with synchrotron radiation. Solution properties are studied as an adjunct to the effective separation of these important HFIR products. Neutron scattering and various spectrophotometric techniques such as Fourier Transform infrared spectroscopy are being used.

Chemical and physical principles underlying the design of more effective multiphase separation processes are being defined. The concept of molecular recognition is being applied in the design, synthesis, and evaluation of novel ligands for separating closely related metal ions by solvent extraction. Incorporation of complexing ability, charge-neutralizing ability, and organophilicity into single multifunctional extraction agents is currently stressed. Related research is focused in improving mass transfer in liquid-liquid processes through the use of high-intensity electric fields; emphasis is placed on understanding the underlying hydrodynamical interactions that lead to augmented performance.

Secondary thrusts lie in the areas of using high-gradient magnetic fields for macromolecular separations and in electro-enhanced vapor-liquid separations. Areas for future investigation include microwave enhancement of reaction/separation systems and geometric and external field effects in sorption, chromatography, and other solid-liquid processes. Studies are also under way on solutions in supercritical solvents that are used as separations media in novel extraction and chromatographic processes. Current work focuses on the equilibrium structure and properties of such solutions. Future studies in this area will include neutron scattering and the prediction and measurement of transport properties.

Many of the existing components of the KC03 basic chemistry program are well postured to contribute fundamental long-range chemical information relevant to the growing national emphasis on environmental remediation and protection and associated waste-related R&D, especially for aqueous systems. A program is under way to study the photochemical reactions and associated photophysics of aromatic molecules in atypical media, such as in aqueous solutions and sorbed on solids. In addition to elucidating fundamental questions of photoreactivity in anisotropic environments, this work should contribute to understanding the transformation of hazardous materials in natural settings exposed to sunlight.

KC04—Engineering and Geosciences

The major effort supported by the Engineering component of the Engineering and Geosciences Program is the Center for Engineering Systems Advanced Research (CESAR). One new engineering initiative is a proposed study of advanced bioprocessing systems for energy production and conservation. An initiative is in preparation which will focus on the elucidation of the theory of interactions for multibody problems in external fields. The effort will center on nonlinear approaches and will emphasize the application of parallel computation in these systems. This will be the centerpiece of a collaboration between ORNL and the University of Wisconsin.

The CESAR project will continue autonomous mobile robot research [the Hostile Environment Robotic Machine Intelligence Experiment Series (HERMIES)] using the small HERMIES-IIB test bed and the recently constructed HERMIES-III, which has significant manipulation capabilities. Funding is expected to increase slightly during the reporting period. New areas of emphasis include the combined use of sensor-guided manipulators and platform mobility and the control and allocation of heterogeneous resources (e.g., multiple cooperating autonomous robots). A collaborative venture with the French Atomic Energy Association will involve a performance comparison of algorithms, software, and hardware used in computer simulations and on mobile robots.

The new waste R&D initiative (see Initiatives section) mentions briefly the role artificial intelligence and robotics might play in this multidisciplinary effort. CESAR is uniquely

positioned to contribute to this initiative because of its focus, since 1984, on the R&D of robotic intelligent machines for operation in hazardous, unstructured environments. Existing relationships with the decontamination and decommissioning effort at the Oak Ridge K-25 Site and ongoing collaboration with the robotics technology development and integration effort for environmental restoration and waste management show that the long-term CESAR commitment to basic R&D in intelligent machines results in the ability to quickly react and contribute to the solution of pressing applied problems.

In the Geosciences Program, fundamental information is sought on the geochemical processes that control elemental and isotopic distributions in the earth's crust. Special facilities for study of high-temperature aqueous and magmatic systems are used to study metal-ion complexing by carboxylates, mineral solubilities and crystallization, stable isotope exchange with minerals, and the thermodynamics of the C-H-O system at extreme conditions. Experimental data are used to model the evolution of natural systems pertinent to DOE geothermal and hydrocarbon energy programs. New acoustic imaging methods for subsurface and magmatic environments are being developed. Possible new initiatives include studies of the occurrence of natural gas in unconventional settings and application of a unique ion-microprobe capability to isotope distribution studies in mineral assemblages.

KC05—Advanced Energy Projects The Advanced Energy Projects Program supports exploratory research at moderate levels, typically for 3-year durations. A project is funded through FY 1991 for research in the development of a high-efficiency solvent-extraction technique using a high-intensity electric field in a new concept called the emulsion phase contactor.

KC07—Applied Mathematical Sciences The Applied Mathematical Sciences Program supports research in parallel-processing algorithms and the development of applied mathematical, statistical, and computational methods for analyses of physical processes. These research activities are supported by an Advanced Computing Laboratory, which provides research computers with a variety of architectures that are in various stages of development. Parallel computers currently in the Advanced Computing Laboratory include an Intel iPSC/2, an NCUBE/4, a Sequent Balance 8000, a Cogent multiprocessor workstation, and an Intel iPSC/860 supercomputer. The latter item has 128 processors and a peak rating 7.6 gigaflops.

The following will continue to be major research areas: sparse matrix computations, performance characterization, basic matrix computations, design and analysis of computational experiments, and the analysis and numerical solution of partial differential equations. Pervasive in this research is the requirement for parallel processing and related software tools to meet the computationally intensive needs of today's computer models. New proposals in KC07 include support for an ORNL/UT Joint Institute for Computational Science and support for research in advanced software technology for high performance computing. A new initiative for ORNL, which is related to the Joint Institute for Computational Science, is the Grand Challenges in Computational Science (see Initiatives section). The expertise developed in the Applied Mathematical Sciences Program will be one of the key foundations for developing this new initiative.

Computer Hardware, Advanced Mathematics, and Model Physics (CHAMMP), the new DOE initiative in KP05 Atmospheric and Climate Research Division, will benefit from the basic program in KC07 and will drive some of its future research activities. The initiative requires new parallel-computing research in numerical methods; software tools; software engineering; statistical analyses; and data storage, retrieval, and visualization. ORNL's researchers in the KC07 and KP05 programs will work closely together to draw upon required expertise.

KD—Energy Research and Analysis

ORNL supports the Office of Energy Research in technical and economic assessments of

alternative energy sources for selected sectors of the U.S. economy. The funding level varies according to the specific needs of DOE but is expected to remain relatively stable. During FY 1990, ORNL examined key issues associated with the effects of acidic deposition on terrestrial and aquatic systems. Future technical and analytic support for assessments of programs in solar and wind energy and coal combustion is planned. ORNL can also provide support for global climate change issues.

KG—Environmental Compliance

The Environmental Compliance funding category was initiated in FY 1985 in response to a compliance inspection by the U.S. Environmental Protection Agency (EPA) and the state of Tennessee that emphasized the need to reduce radionuclide and hazardous chemical discharges to the environment and to accelerate environmental compliance activities on a comprehensive basis. Funding within this programmatic area is being consolidated under the assistant secretary for environmental restoration and waste management; however, the consolidation is still in progress. For this reason, the prior programmatic title has been retained.

This funding category supports work of two types:

- activities necessary for providing ORNL with the capability to be in compliance with environmental regulations and requirements related to ongoing waste-management operations and environmental monitoring; and
- remedial actions associated with inactive sites and facilities resulting from past research, development, and waste-management activities that have resulted from programmatic activities, primarily in the Energy Research area; from multiprogram activities; and, in cases, from activities for which programmatic ties cannot be identified.

A large number of line-item and general plant projects are under way for upgrading or developing systems for collection, treatment, and disposal of radioactive and hazardous chemical wastes and for improving environmental-monitoring capabilities for the site. Operational start-up was completed during FY 1989 of six large tanks and an associated process wastewater collection system that will replace seven unlined impoundments as part of the $18 million Nonradiological Wastewater Treatment Plant line-item project. A treatment plant for removal of heavy metals and organic contaminants from process wastewater was completed during FY 1989 and compliance operation was initiated during mid-FY 1990. Detail design is nearing completion for a $35 million line-item project (Bethel Valley Liquid Low-Level Waste Collection and Transfer) to replace about one-third of the underground collection and transfer system for liquid low-level waste (LLW).

Past research, development, and waste-management activities at ORNL have produced a significant number of surplus inactive facilities contaminated with LLW and/or hazardous chemical wastes. Program KG provides funding to conduct remedial actions at locations in the White Oak Creek Watershed where past practices have contaminated facilities or the environment to levels that require corrective measures. This effort involves substantial amounts of site-characterization work, assessment of alternatives for National Environmental Policy Act (NEPA) compliance, and actual remedial actions.

Significant emphasis is being placed on planning and technology demonstration for underground tanks closure.

KP—Biological and Environmental Research

Goals of the KP program are (1) to study the interaction of energy-related physical and chemical agents with living organisms and the environment, including their transport, chemical transformations, adverse health effects, and ultimate consequences to humans and the environment; (2) to contribute to DOE's Nuclear Medicine Program and other beneficial applications programs; and (3) to transfer research findings and technological developments outside ORNL.

Research areas in biology include mammalian genetics, molecular genetics, protein engineering, carcinogenesis, radiation biology, risk assessment, and chemical interactions and effects. Environmental science research covers biogeochemistry, environmental biotechnology, global environmental chemistry, ecosystem studies, geosciences, hydrology, environmental assessment, theoretical ecology, and landscape ecology. Health and safety research encompasses human health analysis, epidemiology, health assessments, radiation and chemical physics, dosimetry, nuclear medicine, and instrumentation development for sensitive detection and monitoring of chemicals.

In addition, two unique user facilities are supported by the KP program: the Oak Ridge National Environmental Research Park and the Bioprocessing Research Facility. Users of these facilities include staff of national laboratories and industry and students and staff from universities.

The ORNL KP program is one of the broadest multidisciplinary life sciences research programs in the nation and covers a diverse range of both basic and applied studies. Overall, the KP program at ORNL is expected to experience growth in global change research, subsurface sciences, molecular and mammalian genetics, human genome research, and human-health-effects studies in this planning cycle.

KP01—Analytical Technology: Dosimetry Research and Measurement Science One of the important tasks of this activity is the development of radiation exposure-dose relationships through modeling the biokinetics of radionuclides within the body and modeling the deposition of ionizing energy within radiosensitive tissues from these radionuclides and from radiation externally incident upon the body. Such exposure-dose relationships are the cornerstone of radiation protection and also serve an important role in the evaluation of medical diagnostic procedures involving use of radiopharmaceuticals and X-ray machines.

Development of models describing the biokinetics of radionuclides in persons other than a hypothetical young adult male has required a substantial departure from the traditional empirical approach of "curve fitting" of data from a limited number of exposed individuals. As far as is practical, the models currently being developed explicitly depict the tissues and physiological processes controlling the movement or retention of radionuclides in the body. The advantages of a physiologically realistic approach are that it allows (1) incorporation of basic physiological information into the model, (2) realistic treatment of decay products formed in the body, (3) meaningful extrapolation of data from laboratory animals to humans, (4) meaningful analogies between an element of interest and physiologically similar elements, and (5) a linkage between excretion of a radioactive element and movement among body tissues and blood. Biokinetic models, along with age-specific dosimetric models, developed by this work are featured in the first report of the International Commission on Radiological Protection that tabulates data on the organ dose per unit intake for individuals of various ages.

Extensive participation on committees and task groups of the National Council on Radiation Protection and Measurements, the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine, and the International Commission on Radiological Protection provide recognition of the scientific expertise of this program.

Another effort under this activity involves multidisciplinary research targeted toward three major areas: (1) cost-effective chemical and biological screening techniques, (2) biological and chemical sensors, and (3) basic technical advances of emerging monitoring technologies.

We have initiated the development of the second-generation fluoroimmunosensor (FIS). The previous FIS devices were developed for "one-shot" measurements, whereas the second-generation FIS devices are designed to be regenerable. By combining FIS technology with a capillary reagent delivery system, we have constructed microscale sensors that are capable of performing a variety of heterogeneous FIS procedures repetitively, remotely, and in situ. These procedures include

adding solid- or liquid-phase antibody, adding secondary reagents (e.g., the labeled "second" antibody when performing sandwich assays), and rinsing to remove unbound impurities. In addition to delivering reagents, the sensor has the capability of sampling analyte through a membrane via either diffusion or aspiration. The latter mode of sampling could be very beneficial in the eventual use of the sensor for the measurement of large molecules.

We have produced a variety of deoxyribose nucleic acid (DNA) adducts by incubating calf thymus DNA with the appropriate polyaromatic epoxides in vitro. Four different polynuclear aromatic hydrocarbon (PNA) compounds [benz(a)anthracene, dibenz(a,c)anthracene, benzo(a)pyrene, and methylcholanthrene] were used to produce the adducts. Subsequently, the level of adduction for the various PNAs (i.e., PNA residue per unit of base pairs of DNA) was determined using fluorescence to quantify the PNA (hydrolyzed from the DNA by acid) and UV absorbance to quantify the DNA adducts (i.e., nonhydrolyzed, bound to DNA). The synchronous fluorescence technique developed under this activity was found to provide excellent selectivity in identifying the PNAs bound to DNA. Limits of detection by this technique are currently in the range of 1 PNA adduct per 105 to 107 base pairs, and research is under way to extend the detection sensitivity to a lower level of adducts.

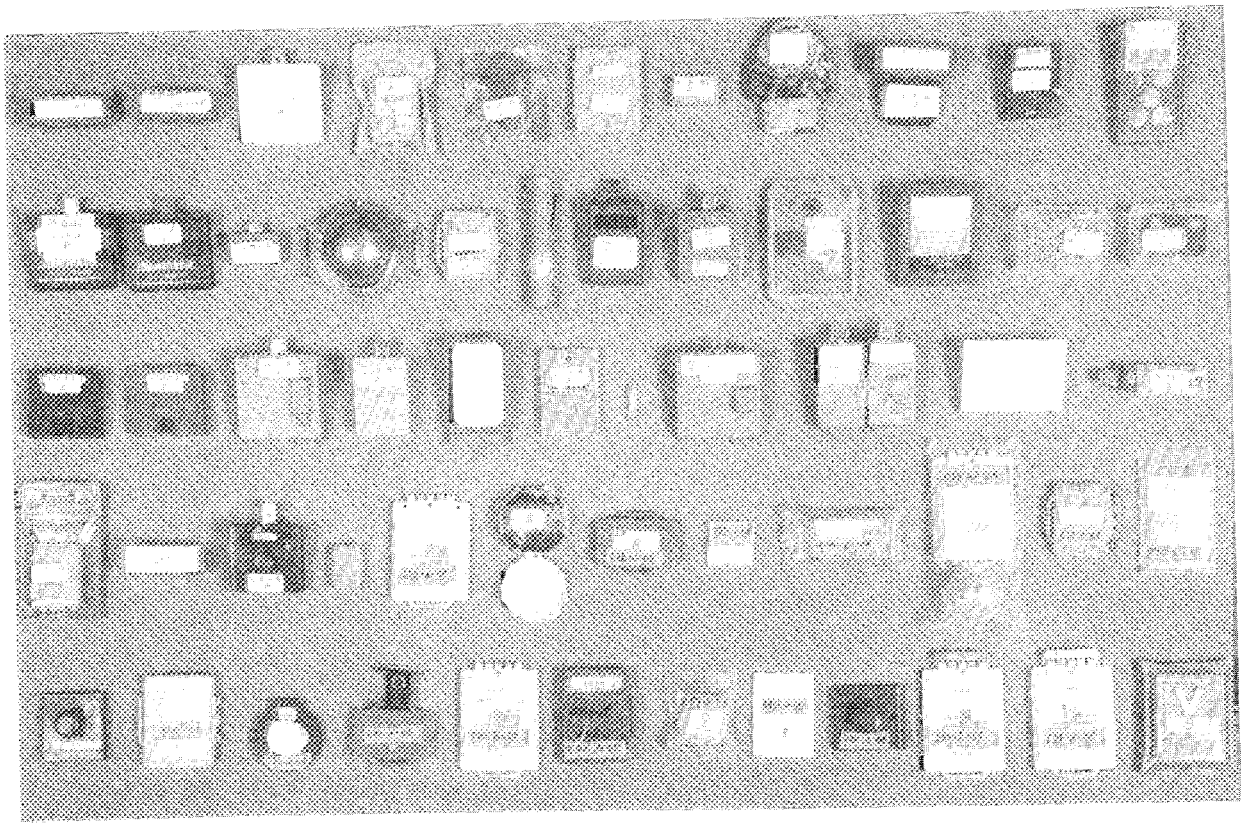
ORNL researchers have international recognition in neutron dosimetry. Annual international personnel intercomparison dosimetry studies at the Radiation Calibration Laboratory (RADCAL) and Health Physics Research Reactor have been a major focus of technology transfer. RADCAL has been outfitted with radiation sources configured to deliver precise doses at specified locations. Although the major emphasis of research may be on personnel radiation dosimetry, the facility will be available for dose-effect test irradiations of small experimental animals. It is planned that RADCAL will become involved not only with personnel dosimetry and radiobiology research activities but also with national dosimeter test programs, teaching and training activities, and expanded dosimetry intercomparison studies (Fig. 24).

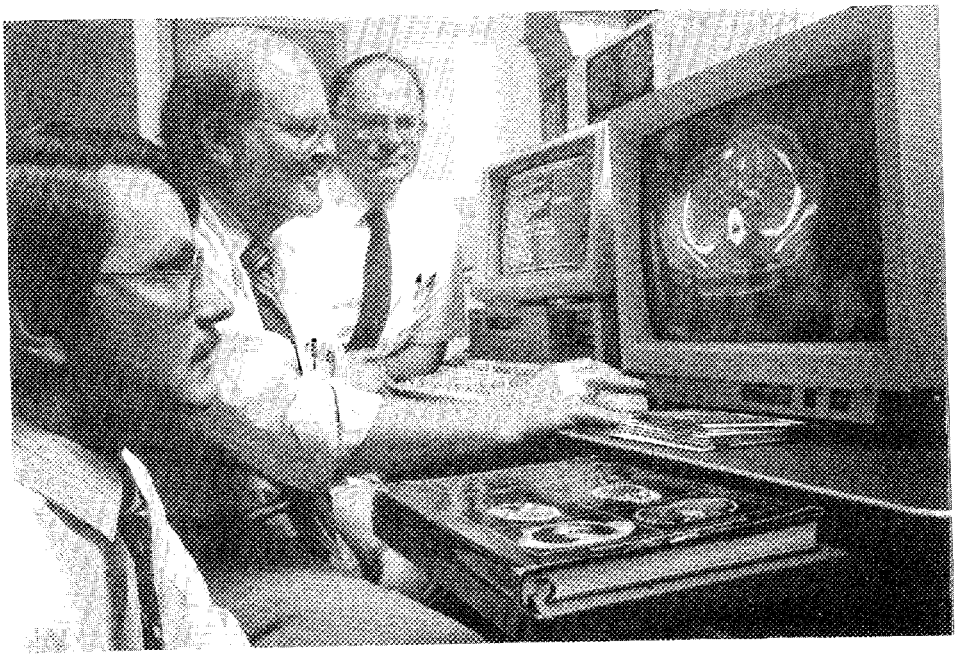
A broad-based research program in the Health and Safety Research Division is directed toward increasing our knowledge of detrimental effects of all types of energy production. Included in this program are research on chemical, biological, and physical agents associated with energy technologies; development of advanced measurement techniques; and development of appropriate assessment and risk-analysis methodologies needed to make balanced estimates of current and future energy strategies.

In the analytical technology area, physical properties of materials of biological or environmental importance, mechanisms that govern transport and chemical transformations of pollutants, and the details of direct interactions of harmful agents with biological materials are studied through a variety of theoretical and experimental techniques. The efforts encompass interactions at the atomic, molecular, and macroscopic levels in solids, liquids, and gases; on surfaces; and at solid-liquid interfaces. Special emphasis is given to interactions in the liquid including Monte Carlo modeling of radiation effects on biological molecules in irradiated matter.

Using software developed by the Geographic Data Section of the Computing and Telecommunications Division, reseachers can examine images of organs of interest to define their shape, size, location, and density. These data are used in radiation transport calculations using Monte Carlo methods to compute the deposition of ionizing energy in radiosensitive organs and tissues of the body from medical and environmental radiation exposures (Fig. 25).

Strong emphasis is given to development of techniques that provide advanced instrumentation for characterizing and sensitively detecting a wide range of chemical species and related biomarkers of health effects. Included in this effort are unique applications of laser optical techniques, ultraviolet and soft X-ray spectroscopic techniques, electron-beam microlithography, electron microscopy, scanning tunneling microscopy, mass spectrometry, and picosecond laser techniques. ORNL's new





program for experimental studies of picosecond processes in liquids, gases, and molecular clusters concentrates on studies of structure and dynamics relevant to energy deposition.

KP02—Environmental Research The goal of the KP02 program is to increase our understanding of the transport, transformation, and effects of energy-related contaminants in the environment. Linkages among the atmosphere, the terrestrial biosphere, and freshwater systems are emphasized to gain a greater appreciation of the fundamental biological, chemical, and physical processes governing the transport and effects of materials in the environment. Basic studies in radon dynamics focus on subsurface source and transport mechanisms.

Environmental Biogeochemistry The ORNL atmospheric research project concentrates on quantifying several aspects of atmosphere/biosphere exchange that are likely to be critical in understanding and predicting the effects of global change. These include wet and dry removal processes and surface emission rates of both natural and pollutant constituents important to tropospheric chemistry and biogeochemical cycling. Major emphasis is placed on determining the interactions of these materials with forest canopies, particularly in complex terrain. New issues being addressed include testing methods for

New Initiative—Advanced Photonics for Environmental Needs

Fueled by the growing global concern over environmental insults, a critical need has developed for the next generation of instrumentation to have a high degree of sensitivity, selectivity, and portability. These needs arise in quantitative studies of waste generation, transport, and remediation as well as global atmospheric problems such as the world energy balance (greenhouse effect), the ozone depletion problem, and the study of airborne pollutants. For instance, the DOE's new Atmospheric Radiation Measurement (ARM) Program will require state-of-the-art remote-sensing instrumentation. Photonics instrumentation, particularly instrumentation involving novel lasers and newly discovered physical principles, is capable of providing "single atom sensitivity" and isotopic, atomic, or molecular selectivity (Table 23). Furthermore, photonics devices are becoming more compact, field-hardened, and in the case of lasers, capable of remote application.

Table 23. Budget projections by fiscal year for Advanced Photonics for Environmental Needs Initiative ($ in millions)

	1991	1992	1993	1994	1995	1996
Total funding	0.5	0.6	0.7	0.8	1.0	1.0

ORNL's Health and Safety Research Division is a leader in developing and using laser technology to study fundamental chemical and physical processes. Responding to the needs of both environmental scientists and waste clean-up specialists, many of these new techniques can be focused on applied measurements. As examples, two ongoing instrumentation development programs are directly linked to needs of ORNL's Environmental Sciences Division (ESD). One has involved a device to measure UV-B penetration in leaves (Fig. 26) and the other a sensitive

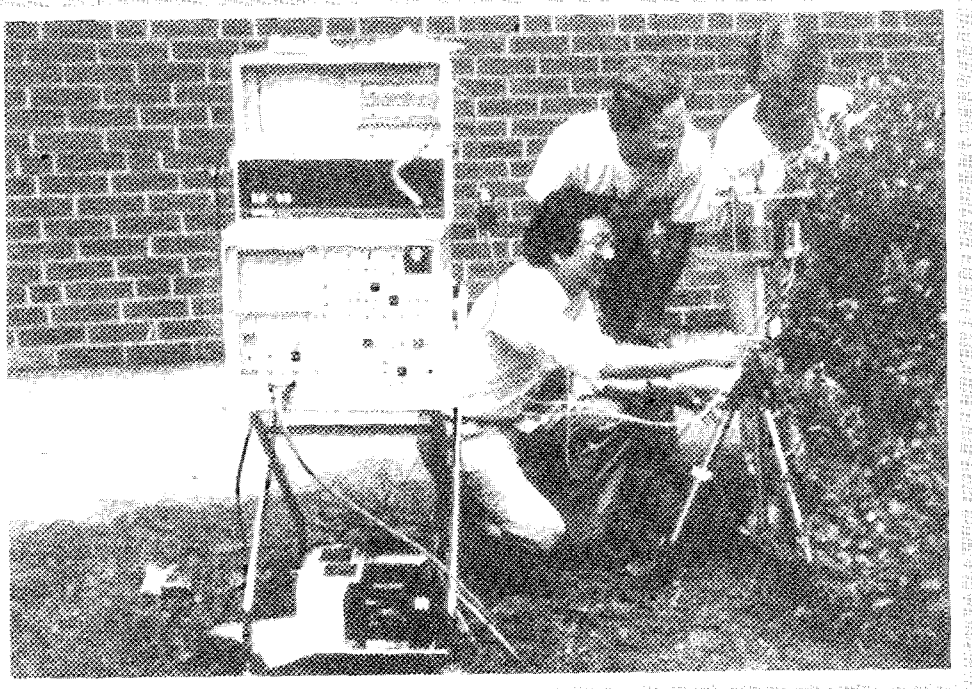


Fig. 26. The fiberoptic microprobe has been developed to measure profiles of UV-B light within plant leaves. UV-B light has increased because of ozone depletion.

optical mass spectrometer for measurement of organics in forest canopies. A third proposed device for laser remote sensing of atmospheric species would address the measurement of greenhouse gases.

This new initiative would be interdisciplinary (chemistry, physics, environmental science) as well as interdivisional in its contribution to solving urgent national problems.

measuring biogenic emissions, the sensitivity of global trace-metal cycles to climate change, and development of models for scaling up surface exchange rates from point measurements. This work supports DOE tasks in the areas of dry deposition, precipitation scavenging, deposition modeling, landscape scaling, biogenic emissions, and biogeochemical cycles.

Marine transport studies involve the measurement of naturally occurring radionuclides (^{7}Be, ^{35}S, and ^{210}Pb), anthropogenic radionuclides (^{137}Cs, ^{239}Pu, and ^{240}Pu), and stable isotopes (^{13}C and ^{18}O) to trace and quantify the dispersal and fate of energy-related materials in watershed, estuarine, and ocean-margin systems. The watershed research is focused on identifying groundwater and surface water sources and on quantifying the extent to which atmospherically derived substances, such as sulfur and lead, biogeochemically interact with drainage-basin soils and vegetation during runoff or snowmelt. The marine research is focused on using biogeochemical tracers to quantify the exchange of materials between the land and sea. This research is important for two reasons: (1) for developing predictive capabilities to assess (over large spatial and temporal scales) the net movement and biogeochemical fate of substances associated with

New Initiative—The Liquid State of Matter

In terms of fundamental knowledge, liquid is the least explored and least understood state of matter. Yet liquid state interactions underlie a wide variety of basic research and applied technologies. Such interactions are of crucial importance in fields as diverse as particle detectors, chemical processes, pollutant transport, and radiation effects in biological cells. Our Liquid State of Matter Initiative will focus on the problem of achieving deep understanding of fundamental liquid-phase behavior with the goal of predicting new phenomena and improving existing technologies (Table 24).

Table 24. Budget projections by fiscal year for The Liquid State of Matter Initiative ($ in thousands)

	1991	1992	1993	1994	1995	1996
Total funding	450	500	560	630	700	800

Research areas will include (1) studies of the optical and electrical properties of liquids, especially transient phenomena using fast laser and electron probes, with application, for instance, to improvements of liquid particle detectors; (2) elucidation of the relation of liquid properties to those of gases and isolated atoms and molecules via studies of gases under extreme pressures and of atomic and molecular clusters, important for understanding the transport of pollutants and nutrients in the environment; (3) studies of the transport of radiation and radiogenic products in the structured water around DNA in a cell, relevant to models of radiation damage and to solving the problem of low-dose effects.

energy-development and waste-disposal activities and (2) for determining their potential effects on terrestrial and marine ecosystems.

Radon The subsurface source, transport, and entry of radon-bearing soil gas into residences is a critical component of environmental radon dynamics. The Health and Safety Research Division has received funding since FY 1987 to study the relevant mechanisms pertaining to houses and geology. These basic studies are designed to understand temporal and spatial fluctuations in indoor levels of radon and to conduct successful mitigation. In the period FY 1987 to 1989, the program was supported jointly by the DOE Office of Health and Environmental Research (OHER), EPA, and the Tennessee Valley Authority (TVA). The DOE funding level will likely remain at $150,000 in FY 1991.

Ecosystem Function and Response The scientific goals of the Walker Branch Watershed Project directly coincide with the type of research identified by OHER as being a critical national R&D need. In particular, one of OHER's missions is to understand the physical, chemical, biological, and geological processes that directly and indirectly control the flux of energy-related contaminants from their sources, through the environment, to sensitive receptors or long-term sinks. The research focus is on the spatial and temporal variations in mechanisms that regulate the storage,

transformation, and transport of critical ecosystem resources such as carbon, nitrogen, and phosphorus. This focus is appropriate because the biogeochemistry of most toxic trace metals and organic contaminants are linked to the transport; fate; and effects of natural organic materials, which are controlled, in turn, by biological utilization and recycling of carbon; nitrogen; and phosphorus.

Research on vegetation response to air pollution stress (particularly O_3, S_x, NO_x, and acid deposition) has achieved national prominence. Our research efforts encompass the role of terrestrial-aquatic linkages in the processing of atmospheric pollutants and changes in stratospheric ozone and the effects of UV-B on biotic resources in terrestrial and aquatic systems. As with most technology-related pollution problems, an interdisciplinary approach is required for planning and conducting the appropriate research. ESD research for OHER focuses on biogeochemical cycling at the watershed scale, with Walker Branch Watershed as a central research facility. Research also addresses atmospheric-deposition inputs, subsurface hydrologic transport, element cycles, and effects in streams.

National Environmental Research Park The Oak Ridge National Environmental Research Park project is being redirected to include networking with the other five DOE parks through the PARKNET system. The project will focus on

- integration and synthesis of existing data across parks, including site-characterization data collected as part of the overall DOE Waste Management Program;
- coordination of activities among parks;
- on-site data management and data organization, including establishment of computer data bases of historic data and coordination with the data-management systems associated with the DOE waste-management activities; and
- activities promoting the parks as a coordinated network of cooperating research sites.

In January 1989, the Oak Ridge National Environmental Research Park was formally chartered as a component of the Man and the Biosphere Southern Appalachian Biosphere Reserve.

Theoretical Ecology Research efforts will increase on quantification of regional landscape patterns and the processes affecting ecosystems at large spatial scales. Our theoretical research has explored some basic properties of scaled systems with a view toward taking advantage of the scaled structure in predicting system dynamics. Theoretical and modeling studies are designed to develop methods for measuring ecological patterns of natural and managed landscapes, relating these patterns to processes, and estimating how these patterns will change as a result of broad-scale disturbances. A major challenge of this work will be the careful development of statistical approaches to the analysis of spatial pattern. New emphasis will be placed on testing and on validation of theory and models through the use of field and remote-sensing data available from the national environmental research parks and through collaboration with other agencies (e.g., the National Park Service and EPA's Environmental Monitoring and Assessment Program).

Continuing Initiative—Subsurface Research

We will continue our work in the areas of hydrology, geochemistry, modeling, and colloid chemistry in support of DOE programs in site-directed subsurface transport of hazardous substances and subsurface microbiology. Research in subsurface sciences is directed toward defining, understanding, and predicting the movement of energy-related contaminants in humid regions with highly organic natural waters. This work, in direct response to the accelerated efforts on the part of

DOE to address the characterization and eventual cleanup of contaminated facilities, is expected to grow significantly because it will represent an essential element in the waste R&D plans (Table 25). Presently, activities at ORNL consist of laboratory and field studies that are integrated with the development and application of hydrologic and chemical transport models

Table 25. Budget projections by fiscal year for the Subsurface Research Initiative ($ in millions)

	1989	1990	1991	1992	1993	1994	1995	1996
Operating	0.7	1.5	2.5	3.3	3.7	4.3	5.0	5.3
Capital	0.1	0.3	0.6	0.7	0.8	0.9	1.0	1.0

(Fig. 27). These studies include research on the role of colloids and microbial populations in affecting subsurface transformation of energy by-products, including mixed wastes; development of user-oriented expert systems for predicting geochemical reactions and transport characteristics; modeling of the spatial heterogeneity of soils; and research on the thermodynamic and kinetic parameters important to contaminant migration at DOE sites. These, as well as new initiatives that are responsive to DOE's waste R&D plans, will continue and will provide a unique and sound foundation for understanding subsurface contaminant migration in a humid environment.

Fig. 27. An Environmental Sciences Division researcher acquires information that is used to calibrate a three-dimensional, multidomain transport model for describing field-scale subsurface contamination migration. Here, a soil water sample is taken during a tracer release study, which is designed to collect water solutes from three different soil-pore domains through the use of fritted glass solution samplers maintained at a variety of tensions.

New Initiative—Environmental Biotechnology

Public awareness of environmental concerns coupled with DOE's focusing attention on past operations has drawn attention to substantial problems associated with waste cleanup activities at the various DOE facilities. While techniques such as capping are currently available, a need exists for developing new techniques that utilize biological systems for mobilizing, stabilizing, degrading, or sequestering contaminants into forms that are not biologically available or hazardous. ESD, working with the Analytical Chemistry; Chemical Technology; Health and Safety Research; and Energy divisions and with the University of Tennessee, is leading the development of such systems (Table 26).

Table 26. Budget projections by fiscal year for the Environmental Biotechnology Initiative ($ in millions)

	1990	1991	1992	1993	1994	1995	1996
Operating	5.2	6.0	7.2	9.0	10.1	11.0	12.0
Capital	0.3	0.5	0.8	0.4	0.5	0.6	0.6

The DOE Subsurface Transport Program has provided support for basic research related to microbial processes for the past several years, and it serves as an impetus for several components of this initiative. Basic research on contributions from molecular biology will include identification of genetic loci in microbial systems demonstrating biodegradation activity, including mechanisms of expression, gene enhancement, and biochemical reaction processes. Research in toxicology is directed towards development and refinement of more cost-effective tests for identifying and prioritizing contaminants requiring removal or treatment. Biological monitoring continues to be a major focus of this area. Studies are ongoing at all three Oak Ridge facilities and at Paducah and Portsmouth. Through comparison of data gathered in these studies with results of remediation activities that have already taken place, efficacy of various cleanup activities can be determined. Utilizing R&D developments in applied waste technology is affected by policy analyses that establish federal guidelines of acceptability of biotechnological advances. These technologies will also be available for transfer to other DOE facilities. ORNL expertise in social sciences and economics will be used in conjunction with R&D advances to contribute to the decision-making process. Methods that enable early detection of environmental health problems are needed. We will continue to work closely with EPA in the Environmental Monitoring and Assessment Program as we continue to develop our own suite of indicators.

The utility of aquatic biomarkers for assessing environmental health and recovery of receiving systems will continue to be evaluated and expanded (Fig. 28). New research evaluating plants as biomarkers has been undertaken. Development of microbial markers and gene probes is proceeding with organic and trace metal contaminants at waste sites. Efforts in bioremediation focus on developing an understanding of the environmental processes affecting rates of contaminant degradation and/or mobilization. Research is directed at recalcitrant organics and mixed waste types. Testing of available bioreactors and construction of new reactors will enable rapid

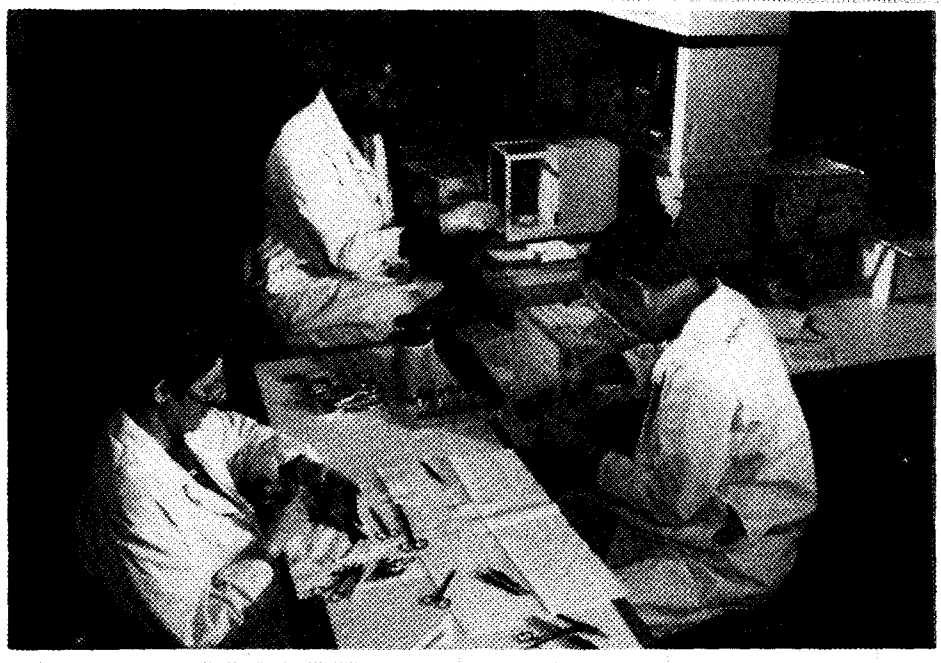


Fig. 28. Researchers in the Environmental Sciences Division perform biological-indicator studies to determine the effects of environmental stress on aquatic streams and reservoirs.

application of existing technologies. Modification of these environments in bioreactors, as well as in situ will enable application of these techniques to DOE field sites. We anticipate that increased efforts in environmental biotechnology will be applied to DOE's immediate problems, and expansion of these activities in the basic research plan supporting environmental restoration is required.

KP03, KP04—Health Effects and General Life Sciences Common themes within these activities are interactions of animals, cells, and molecules with their respective environments. Emphasis will concentrate on three programmatic areas: mammalian genetics, protein engineering, and radiation carcinogenesis. ORNL proposes that the theme of molecular and mammalian genetics, a unique national resource and central to the DOE mission, be recognized as a major programmatic focus (initiative) and that strategic plans be developed for expansion.

Mammalian Genetics In mammalian genetics research, increasing emphasis will be placed on molecular techniques for genome studies. These techniques include in vitro insertional mutagenesis (Fig. 29) and in vivo saturation mutagenesis. Both of these experimental approaches will yield structural and functional information for genes in the mouse that can be applied directly to the human genome initiative. The molecular characterization of DNA damage and repair, together with the analysis of mutations and chromosome alterations, is crucial to the understanding of some of the mechanisms of induction of mutational events. Human cytogenetics will continue to play a major role in identifying mutagenic pathways. Increased

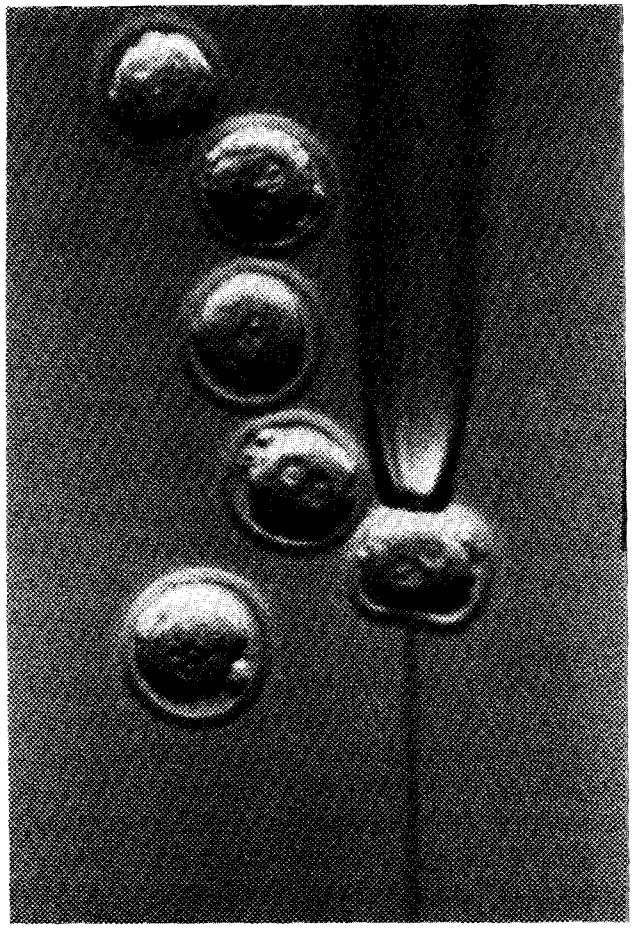


Fig. 29. Actual photo of a mouse ovum being injected with DNA from a microsyringe.

emphasis will also be placed on mouse models for human developmental anomalies and specific genetic disorders.

Recent accomplishments highlight the mammalian genetics program. (1) Partial functional mapping was completed of a region of mouse chromosome 7 that is linked to developmental abnormalities. (2) Discovery was made of a mouse mutant that provides a model for immune-mediated diseases in humans. (3) It was demonstrated that specific chromosomal aberrations, associated with initiation or progression of tumors, are produced by genomic recombination. (4) Transgenic mice were produced as a model system for sickle cell hemoglobin.

Closely aligned with mammalian studies, molecular genetics will include investigations of genomic structure, regulation of gene expression, and structure and function of gene products. Researchers at ORNL have the capability to visualize higher-order chromatin structure and the three-dimensional structure of nucleosomes (the core particle of chromatin) by using X-ray and neutron diffractometry and special techniques in electron microscope tomography developed at ORNL. Cloning of segments of the eukaryotic genome and their subsequent sequencing are providing new insights about the nature of regulatory elements of DNA and the propensity of small regions of DNA to undergo spontaneous mutations.

Protein Engineering Protein engineering (site-directed mutagenesis) represents the use of recombinant DNA technology to systematically alter the structure of proteins by replacement, addition, or deletion of amino acids in targeted regions. In the scant 8 years since its inception, protein engineering has emerged as the most powerful tool for probing structure-function relationships and has opened exciting new vistas for optimizing properties of proteins for medical, industrial, and agricultural applications.

In terms of breadth and integration of many activities in molecular genetics and biochemistry, ORNL's program in protein engineering is unique among DOE laboratories. Current efforts center on several functionally diverse proteins: ribulose bisphosphate carboxylase/oxygenase (Rubisco), the CO_2-fixing enzyme and a determinant of biomass yield; epidermal growth factor (EGF), a polypeptide hormone that stimulates cellular growth and differentiation; and O6-methylguanine-DNA methyltransferase (Ada), a protein that repairs mutagenic lesions in DNA caused by alkylating agents. With respect to Rubisco, there are two compelling reasons for carrying out site-directed mutagenesis: (1) despite the absolute dependence (direct for plant and

indirect for animals) of all higher life forms on the enzyme, many mechanistic questions remain unanswered, and (2) if the enzyme's oxygenase activity, detrimental to net CO_2 fixation, could be reduced, major increases in plant productivity might be achieved.

Several extracellular protein factors are capable of stimulating the growth of cells and the expression of specific genes believed to be involved in the entrance of mammalian cells into and progression through the cell cycle. One of the most highly studied among these is EGF, a 6-kDa single polypeptide chain with three internal disulfide bonds, which initiates its action through high-affinity ligand binding to the specific cell-surface EGF receptor. In response to EGF, the receptor undergoes autophosphorylation on tyrosine residues by its intrinsic protein kinase activity, which also phosphorylates exogenous substrates. This triggers a cascade of biochemical events, including increased glycolysis and protein synthesis and increased transcription of specific genes that ultimately lead to a stimulation of DNA replication and cell division. Some aspects of the function of EGF can be addressed by site-directed mutagenesis of the human gene that we have synthesized and cloned in *E. coli.*

The ubiquitous and unique Ada protein is responsible for the repair of O_6-alkylguanine, a promutagenic and procarcinogenic lesion in DNA produced by many alkylating mutagens, including N-alkylnitrosamines. This protein, in a suicide reaction, reacts stoichiometrically and irreversibly, whereby alkyl groups from DNA are transferred to cysteinyl sulfhydryl groups of the protein itself. The molecular basis for the multiple and disparate functions of the Ada protein are being studied by site-directed mutagenesis of both the structural and regulatory regions of its gene, already cloned and sequenced. Additional gene products under close scrutiny include enzymes involved in transcription of DNA and membrane-transport proteins responsive to environmental insults.

Recent accomplishments illustrate progress made in the protein-engineering program. (1) Site-directed mutants of human EGF were constructed that exhibit differential changes in receptor binding and elicitation of kinase activity. (2) It was demonstrated that site-directed mutant enzymes can be used to correlate the role of active-site residues with discrete steps in an overall catalytic pathway. (3) By a novel complementation approach, two human-DNA repair proteins were cloned—O6-methylguanine-DNA methyltransferase and N-methylpurine-DNA glycosylase.

Radiation Carcinogenesis Cancer studies continue to combine the investigations that elucidate mechanisms with those aimed at the practical problem of risk estimates, especially for high linear-energy-transfer radiation. The control of gene expression is cardinal to development, differentiation, and normal function. Perturbation in the control of gene expression is characteristic of neoplastic change.

Radiation is used to determine the role of specific molecular and chromosomal alterations in the induction of leukemia. Studies at different levels of biological organization are being conducted to characterize the relationships of radiation quality and cancer induction and susceptibility and genetic background, which form a keystone in the development of methods for extrapolating across species. The initiation events that convert normal cells to potential cancer cells are an essential stage in carcinogenesis but do not determine whether or not an overt cancer develops; host factors are responsible. Therefore, the studies of the factors that influence whether an initiated cell progresses or its expression is suppressed are central to the problem of carcinogenesis in general and radiation-induced cancer in particular. Thus, studies on the mechanisms of cell-cell interaction and the involvement of factors such as transforming growth factor type B in control of neoplastic growth will continue.

Leukemias are the quintessential radiation-induced cancers in humans. In the case of myeloid leukemia, chromosome aberrations are associated with the disease in both mice and humans. The ORNL studies of myeloid leukemia are divided into two categories: studies of mechanisms and

studies related to risk estimates. These studies have five objectives: (1) to establish whether the aberration of chromosome 2, frequently found in leukemia cells, is the only aberration involved and, if not, to identify the relevant lesion; (2) to identify the molecular changes involved and their role in the mechanisms, in particular, altered expression of interleukin genes; (3) to establish the causal relationship between induced specific aberrations and the specific leukemia; (4) to determine the reduction in risk of radiation-induced leukemia with reduction in dose rate; and (5) to determine the leukemogenic effect of protracted exposures to fission neutrons.

The answers to these questions, particularly the effect of dose rate, are central to risk estimates, which cannot be obtained from human data. These answers will permit testing of a promising method of extrapolation across species. The experiments will also establish the similarities and differences in the mechanisms of myeloid leukemogenesis between humans and mice.

Considerable publicity has been given to the likelihood of greatly increased incidences of skin cancer as a consequence of elevated UV-B associated with chlorofluorocarbon-catalyzed depletion of stratospheric ozone. Surprisingly, reliable quantitative data of historical fluxes of UV-B intensities do not exist; hence, correlations between ozone depletion and enhanced UV-B radiation at the earth's surface have not been determined. Experiments have been initiated to examine the feasibility of using purified DNA to quantify UV-B radiation; the measured endpoint is production of thymine dimers in DNA induced by UV-B.

Recent accomplishments in radiation carcinogenesis by the Biology Division underscore the importance of this program. (1) Transgenic mice that carry the gene for interleukin-3 were produced so that its role in radiation-induced leukemia can be evaluated. (2) Laboratory simulation experiments were shown to markedly underestimate the extent of DNA damage induced directly by sunlight. (3) Cell-cell interactions were shown to modulate the expression of neoplasia induced by low-linear energy transfer radiation, such as X-rays and gamma rays. Ultraviolet radiation was demonstrated to act synergistically with ionizing radiation in the production of skin cancers.

In other work in health effects, a comprehensive update of the "Reference Man" data, used extensively in the radiation-protection community, is nearing the review stage. This revision is the first major revision in 20 years and is being conducted as a task group of the International Commission on Radiological Protection, Committee 2.

Continuing Initiative—Genome Mapping and Sequencing

An expanding initiative entails mapping of regions of the mouse genome, which are in part homologous to the human genome, and developing new or improved methods for DNA sequencing. The major objective is to explore the structural and functional characteristics of the mammalian genome by use of experimental molecular genetics. Experimental plans include the following:

- development of complete molecular maps and refined functional maps of several specific regions of the mouse genome;
- analysis of the molecular structure and effects of heritable, agent-induced mutations;
- creation of molecularly tagged mutations throughout the murine genome by insertional-mutagenesis techniques;
- utilization of mutagenesis protocols that generate deletion mutations to expand the genomic regions accessible to molecular-structure analyses;

- application of mutagenesis techniques to screen for models of important human genetic disorders that can then be analyzed molecularly; and
- utilization of concurrent computing for high-speed DNA sequence pattern analysis.

This initiative integrates genetic functional analyses with molecular mapping. Indeed, molecular chromosomal mapping of mouse genes will not stand alone as a sterile catalog; all molecular information will be correlated with functional information. Structure-function analyses of specific murine genomic regions will also facilitate characterization of homologous regions of the human genome. Recent accomplishments include the design of genomic probes for the agouti locus (which affects embryonic development, fertility, kidney function, and susceptibility of neoplasms) of mouse chromosome 2; and the demonstration of the usefulness of chlorambucil, a chemotherapeutic agent, in generating deletion mutations at high frequency.

The mapping activities are complemented with a multidisciplinary effort, involving several divisions at ORNL and the private sector, to develop novel methodologies for elucidating specific DNA sequences. This program uses high-sensitivity isotope-detection instruments originally developed at ORNL. The current focus is on the development of nonradioisotope DNA-sequencing technologies that will markedly increase the rate of sequence acquisition and will promote the automation of this procedure.

High-speed DNA sequence pattern analysis will be developed using concurrent computing. The growing amount of DNA sequence data generated by laboratories worldwide makes it necessary to develop, test, and evaluate fast methods for DNA sequence pattern analysis. These methods will be used to find biologically important features in the raw sequence data, and to combine these features to produce high-level symbolic information about the sequence. The purpose of the effort at ORNL is to concentrate expertise in molecular biology, artificial intelligence, and concurrent computing in order to develop innovative methods for DNA pattern analysis that make use of the latest available parallel computing technology.

Budget projections for the Genome Mapping and Sequencing initiative are shown in Table 27. Total funding includes DOE and work-for-others (WFO) funding for this ORNL multidivisional program.

Table 27. Budget projections by fiscal year for Genome Mapping and Sequencing ($ in millions)

	1989	1990	1991	1992	1993	1994	1995	1996
Operating	1.0	1.4	7.9	8.7	9.5	10.4	11.4	11.4

Continuing Initiative—Structural Biology

An interdivisional (Biology, Health and Safety Research, and Solid State divisions) effort is intended to develop support for structural biology through OHER. A core proposal which includes biological applications of small-angle neutron scattering, small-angle X-ray scattering, neutron crystallography, and X-ray crystallography is now under review by OHER. Currently,

crystallographic studies of nucleosomes (Fig. 30), the building block of chromatin, are partially funded by OHER. Nucleosomes, reconstituted from a cloned DNA restriction fragment, have been crystallized in a form suitable for high-resolution analysis. Other crystallographic projects would

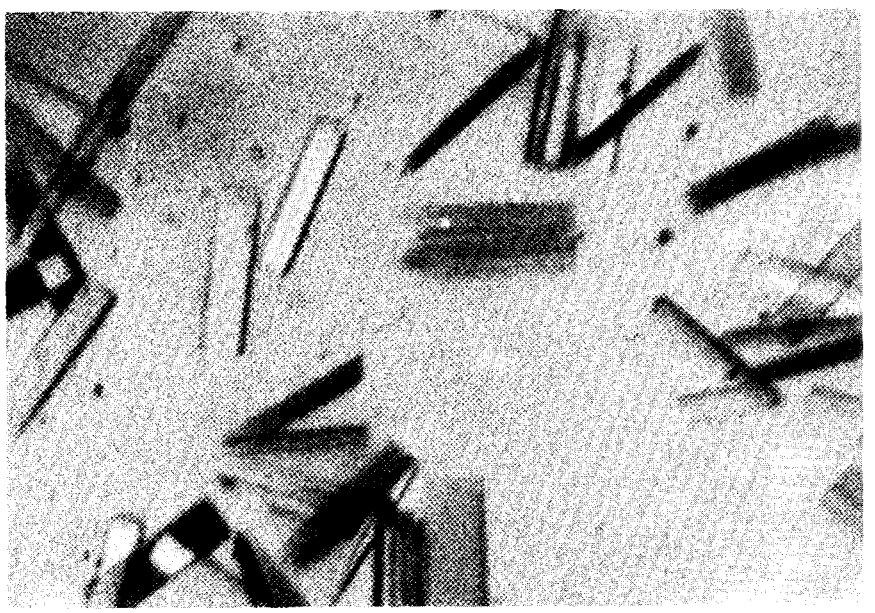


Fig. 30. Photomicrograph of nucleosome crystals containing a human α-satellite-defined sequence DNA and purified histones. The crystals are birefringent; display sharp, well-formed edges; and show very clean crystal faces. The larger crystals in the survey approach 0.4 × 0.15 × 0.15 mm. Diffraction experiments that will lead to a high-resolution crystal structure of the nucleosome core particle, the fundamental building block of chromatin, are in progress.

entail three-dimensional structure determination of human EGF and mutant analogs designed by ORNL's Protein Engineering Program as well as a human DNA repair protein that removes alkylation lesions.

Biological small-angle neutron and X-ray scattering research was initially funded as a component of the NSF-supported National Center for Small-Angle Scattering Research. Because of the HFIR shutdown, National Science Foundation (NSF) withdrew its funds and restoration is unlikely. The restart of HFIR compels the establishment of core support from OHER to maintain structural biology research at these national resource facilities and to continue an ORNL program as the basis for developing structural biology programs at the ANS (Table 28). OHER funding is

Table 28. Budget projections by fiscal year for the Structural Biology Initiative ($ in millions)

	1990	1991	1992	1993[a]	1994	1995	1996
Operating	0.2	0.2	2.1	2.6	2.6	2.6	2.6
Capital	0.0	0.7	0.7	0.7	0.8	0.8	0.8

[a]Increment required for design of biological instrumentation for ANS.

needed for three on-line scattering instruments ($45 million), equipment for a biological sample-preparation laboratory ($1 million), and a deuterium-labeling laboratory ($1 million) to ensure world-class facilities to users from the biology community.

Continuing Initiative—Human Health Risk Analysis

Continued attention and focus on health risk analysis is expected as DOE and other federal agencies devote considerable resources to environmental restoration. Although most past support and a large fraction of expected support for health risk analysis activities has come or will come from work-for-others (WFO) funding, support for DOE activities is projected to increase as new DOE needs and efforts become formalized. The need to obtain maximum benefits from limited resources, while protecting human health and the environment, will place increasing dependence on high-quality health risk analysis. Our Human Health Risk Analysis Initiative is focusing on necessary research required to develop improved health risk analyses for cost-effective remediation of hazardous waste sites. The initiative focuses on four main areas: (1) risk-assessment methodologies; (2) field applications in support of cost-effective remediation alternatives; (3) evaluated toxicological data systems for risk analysis; and (4) laboratory research, including development of cost-effective instrumentation and bioindicators of exposure and effects. Active involvement in organizing and participating in technical meetings and symposia, an integral part of our initiative, will help to broaden the acceptance of health risk analysis as a tool in managing environmental restoration. Total funding for the initiative is shown in Table 29; DOE would fund about 30% of the total.

Table 29. Budget projections by fiscal year for the Human Health Risk Analysis Initiative ($ in millions)

	1989	1990	1991	1992	1993	1994	1995	1996
Operating	2.0	4.5	6.0	8.0	10.0	12.0	12.0	12.0

KP05—Carbon Dioxide Research In the area of global environmental concerns, ORNL has become a center of expertise in the investigation of ecological transport and effects of chemicals in the environment and in the assessment of hazardous wastes, the global carbon cycle related to CO_2-induced climate change, and acid-deposition issues. These activities are the foundation for the ORNL Center for Global Environmental Studies, which is housed in ESD and involves staff from several other ORNL divisions as well as outside collaborators.

Resource Analysis A program area in Resource Analysis, being managed by ORNL's Carbon Dioxide Information and Analysis Program (CDIARP), is supporting the studies that DOE's Carbon Dioxide Research Program is conducting on the effects of increasing CO_2 and changing climate on natural and societal resources. Measures that society might take in response to those effects are also being examined. The major tasks managed by CDIARP include assembling and ensuring the quality of data bases used in these studies, evaluating the potential effects of

CO_2-climate change on environmental resources, and developing methodologies for using climate model output in effects studies.

Global Carbon Cycle The main objective of the Global Carbon Cycle Research Program is to develop a scientific basis for predicting changes in atmospheric CO_2 concentrations in response to continued releases of CO_2 by fossil-fuel combustion. Future activities will encompass more research that focuses on terrestrial and oceanic carbon dynamics, global carbon-cycle modeling, and the potential for positive feedback to dramatically alter our current understanding of the carbon cycle. Research will concentrate on multidimensional models of the global carbon cycle, which will yield various estimates of atmospheric CO_2 when given different levels of fossil-fuel use and other variables relating to biogeochemical dynamics. Integration of the research with other collaborators is necessary to develop the information and models needed to provide accurate projections of CO_2 buildup in the atmosphere, from both natural and human sources, during the next century.

Carbon Dioxide Information Analysis Center The objective of the Carbon Dioxide Information Analysis Center (CDIAC) is to compile, evaluate, and distribute CO_2-related information in support of the program. In the coming years, the center's research activities will reflect the new directions of the program. One area of emphasis will be on computer systems development for compiling, analyzing, and handling data for DOE's ARM Program. The center's activities will include research in all aspects of the CO_2 issue and technical management responsibilities in the national CO_2 program.

Computer Hardware, Advanced Mathematics, and Model Physics The objective of the CHAMMP initiative is to develop an Advanced Climate Model employing the hardware and software capabilities offered by emerging computer architectures to improve the mathematical methods currently needed in general circulation models (GCMs) and to address the challenging physics of understanding the climate system. In the near term, CHAMMP will achieve improved GCM performance by taking advantage of existing parallel computers such as ORNL's iPSC/860. ORNL scientists are working in collaboration with staff from Argonne National Laboratory and the National Center for Atmospheric Research to develop a working parallel atmospheric circulation model with terrestrial dynamics.

Carbon Dioxide Effects The responses of temperate forests to enrichment of the atmosphere with CO_2 are unknown. Supporting DOE Direct Effects research, ORNL scientists have shown that growth of tree seedlings increases as the CO_2 concentration rises, but the testing of hypotheses about the long-term responses of forest ecosystems to CO_2 enrichment requires longer-term experiments with a focus on physiological and ecological processes. Future research will improve knowledge of critical mechanisms governing ecosystem responses to atmospheric CO_2, which will lead to a more realistic assessment of the role of terrestrial CO_2 responses in global carbon cycle research than is currently available.

Atmospheric Radiation Measurement The objective of the ARM Program is to provide an experimental test-bed for studying important atmospheric effects, particularly cloud and radiative processes, and for testing parameterizations of these processes for use in atmospheric models. CDIAC staff are assisting DOE in the development of computer and data analysis systems capable of handling the massive amounts of data anticipated over the 10-year lifetime of the program.

KP06—Medical Applications

Nuclear Medicine Research conducted in the Nuclear Medicine Program focuses on the design and development of new tissue-specific radiopharmaceuticals for diagnosis and therapy. New radiolabeled agents are distributed internationally to approximately 20 medical cooperative programs at clinics, universities, and other research institutions for further collaborative preclinical testing and clinical evaluation.

Iridium-191m (half-life 4.9 s) from our osmium-191/iridium-191m generator has important applications for the diagnosis of heart disease and allows rapid, repeat studies with low

radiation exposure. Clinical trials are in progress through our medical cooperative programs in Belgium and West Germany, and over 600 patient studies have been performed. This generator has been licensed recently to Scintillation Technologies, Inc., for commercial applications. Our iodine-123-labeled ("BMIPP") methyl-branched fatty acid is also in clinical trials. This agent is an important tool in cardiology research and is used for the evaluation of differences in regional myocardial blood flow (perfusion) and fatty acid energy substrate uptake by single-photon computerized tomography.

New radiolabeled maleimide agents for labeling antibodies and other proteins for diagnostic and therapeutic applications are being further developed. The (p-iodophenyl) maleimide (IPM) has been licensed to E. I. du Pont de Nemours & Company for research applications. Monoclonal antitumor antibody labeling studies with radioiodinated IPM conducted in conjunction with medical cooperative investigators have demonstrated good labeling yield and very low loss of radioiodide in tumor-bearing animals. New maleimide analogues have also been prepared for easier introduction of radioactive iodine to this agent.

New methods are also being developed for synthesizing bifunctional chelates for attaching radioisotopes of copper (^{64}Cu and ^{67}Cu) and rhenium (^{186}Re and ^{188}Re) to antibodies for therapy and diagnosis. Our studies with ^{64}Cu-chelate antibody complexes are directed at developing an agent for tumor detection with positron emission tomography.

The development and use of radionuclide generators continue to be important focuses of the program. Studies with the tungsten-188/rhenium-188 radionuclide generator system developed in our program are continuing to assess approaches for attachment of ^{188}Re to antibodies and particles for a variety of therapeutic applications. There is widespread interest from both commercial manufacturers and cancer researchers in the use of ^{188}Re, which decays with the emission of high-energy electrons. An additional new generator system under development is the osmium-194/iridium-194 system. Extension of this work is expected to represent the first study of potential applications of ^{194}Ir for therapy.

Radiation Effects The proteins on the surface of cells are tissue-specific and may be altered in kind and amount in the carcinogenic process. Monoclonal antibodies have been developed that recognize epitopes on a glycoprotein (P112), which is expressed exclusively by lung endothelial cells. This apparently unique glycoprotein provides opportunities for the use of the monoclonal antibodies for imaging both the vasculature and tumors. Lipsomes can be targeted with these monoclonal antibodies with the possibility of targeting chemotherapeutic agents. The potential for these applications will be exploited in the light of basic studies of the surface proteins and their expression in normal and cancer cells.

KS—Superconducting Super Collider

Research in support of the SSC is being performed on nuclear collision models and detector preamplifers, both of which relate to calorimeter detection systems design. Work in support of the SSC is expected to increase rapidly (see Initiatives).

KT—University and Science Education (Formerly KE)

In FY 1989, through the ORNL-obligated portion of the KT program, financial support was provided to over 250 student and faculty research participants under a variety of programs, including the science semester programs, nuclear-engineering training experiments, and health physics internships. The KT program also sponsors visits to ORNL by minority educational institution (MEI) faculty and promotes other activities that encourage university involvement in ORNL missions. Two areas of special emphasis in the KT program at ORNL are providing opportunities for

participants from MEIs and expanding precollege programs. In FY 1989, the KT program supported the summer appointment of over 30 faculty and students from MEIs. The program also helped support the operation of the Environmental and Physical Science Study Center (EPSSC), a program for students in kindergarten through twelfth grade that offers field study modules in environmental science at the Oak Ridge National Environmental Research Park and modules in the physical sciences. In FY 1989, over 16,000 students and teachers participated in the EPSSC program, and demands continue to outstrip available resources. A new program to support high school science education teachers through summer research opportunities has also been developed. The program, the Science Teacher Residency Program, was designed to improve the quality of science and mathematics teaching.

Several other initiatives are under way in the area of precollege programs, such as collaboration with local school systems, including support for the Clinch River Environmental Studies Organization (CRESO). CRESO is an organization involving students and teachers from surrounding areas dedicated to student-based, long-term research activities. The ORNL Office of Science Education Programs and External Relations provides financial and technical resources for CRESO, seeing its mission as an extension to the EPSSC. ORNL also started a Saturday Academy for Computing and Mathematics, in which selected high school seniors from six area schools and their teachers meet at ORNL facilities for hands-on learning experiences.

ORNL is the lead laboratory in an effort involving five other DOE laboratories in a national Science Teacher Enhancement precollege program sponsored by the NSF.

ORNL will continue to focus on MEI interactions, with an increasing role expected for Hispanic institutions as the result of two agreements, a memorandum of understanding signed with the University of Puerto Rico and the memorandum of understanding involving three DOE laboratories and three MEIs, including two of Hispanic origin. The Science and Technology Alliance will foster involvement of these educational institutions in long-standing broad program activities that encourage the participation of university students and faculty in ORNL research.

Assistant Secretary for Nuclear Energy

The Assistant Secretary for Nuclear Energy is the major sponsor of applied nuclear research at ORNL (Table 30). Programs funded through this office are multidisciplinary and include nuclear energy R&D, remedial actions, uranium enrichment, and isotope production.

AF—Nuclear Energy R&D

Consolidated Fuel Reprocessing Program The Consolidated Fuel Reprocessing Program focuses primarily on a broad 5-year collaboration with the Power Reactor and Nuclear Fuel Development Corporation (PNC) in Japan. This collaboration, begun in FY 1988, supports PNC's effort to develop and demonstrate technology for reprocessing breeder fuel. The program stemmed from the recognition by Japan of the advanced state of this technology at ORNL and the retrenchment in the U.S. programs in this area. PNC and DOE are each contributing $5 million per year to the base R&D program. In addition, specific hardware is being designed and built in the United States both for the development program here and for the demonstration project in Japan (Figs. 31, 32, and 33). To date, Japan has fully committed $5.9 million for this project. Approximately $9 million more is expected over the next 3 years for hardware, and additional money for engineering services both by ORNL and with a U.S. architect/engineering firm is probable.

The program of collaboration with PNC in liquid metal reactor (LMR) reprocessing has expanded into a broader program of support to PNC efforts to design, construct, and operate the

Recycle Equipment Test Facility (RETF) in Japan. A follow-on phase (Phase II) has been discussed and will begin FY 1993, during which ORNL will continue to provide assistance to the RETF and continue agreed-upon R&D efforts, supporting both RETF and future Japanese plants. Phase III (1997–2003) will encompass the operation of the RETF and will begin a return of

Table 30. Assistant Secretary for Nuclear Energy major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1989	1990	1991	1992
AF	Nuclear Energy R&D	32.4	32.8	43.1	52.6
AH	Remedial Actions and Waste Technology Programs	5.0	5.5	3.3	1.9
AJ	Naval Reactors	*b*	*b*	*b*	0.1
CD	Uranium Enrichment[c]	0.5	8.5	8.9	9.4
ST	Isotopes		14.8	8.0	7.5
Total		37.9	61.6	63.3	71.5
Percentage of total Laboratory funding—BA		7.9	12.0	9.4	9.8

[a]Figures include operating BA, capital equipment, and construction, if any.
[b]Less than $0.1 million.
[c]Applied Technology Division included in 1990 and beyond.

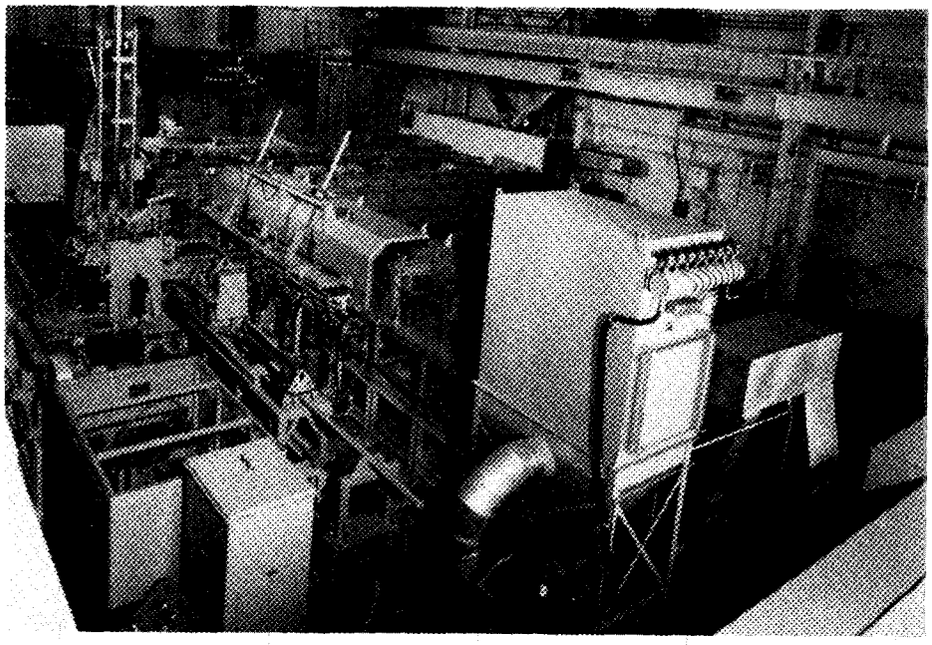


Fig. 31. A laser disassembly system similar to this will be designed and built for hot operation in Japan's Recycle Equipment Test Facility.

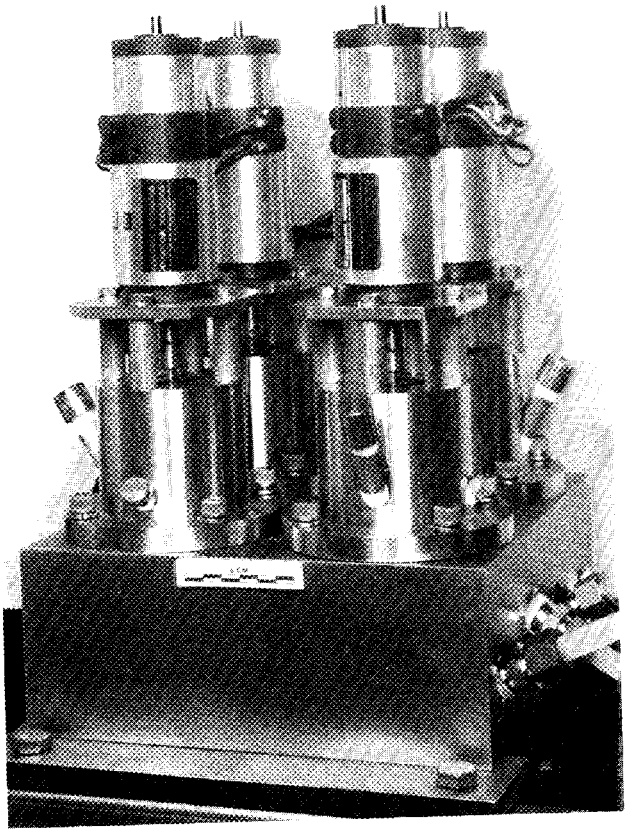


Fig. 32. A centrifugal contactor system (up to 100 units) will be designed and built for hot operation in Japan's Recycle Equipment Test Facility.

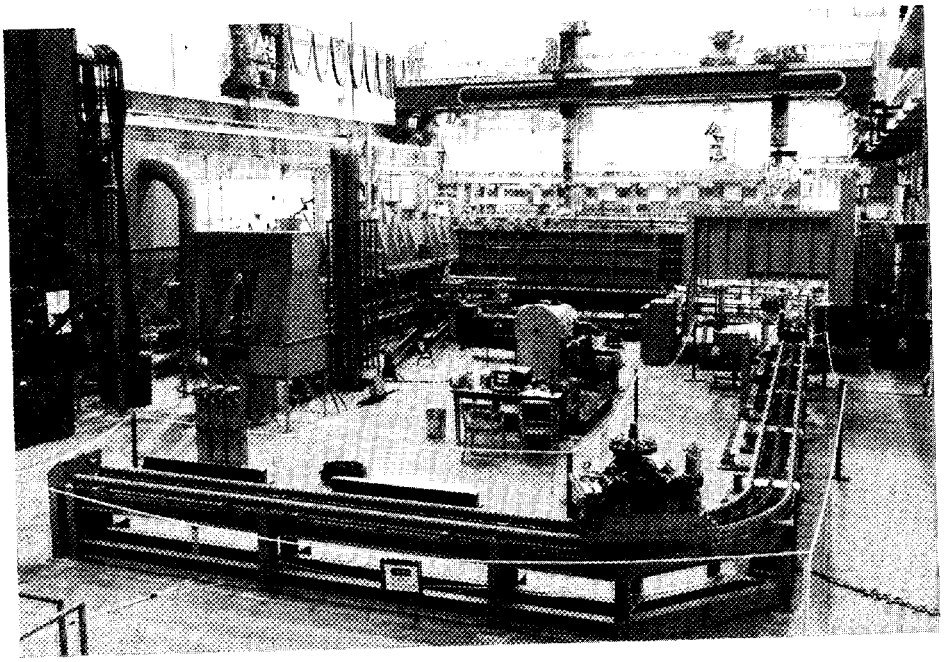


Fig. 33. Robotic sampler developed for testing in Japan's EDF-III facility at Tokai-Mura.

technology from Japan to the United States (based on RETF operating experience) to help maintain U.S. capability and expertise in this technology area.

The benefits are complementary for both Japan and the United States. PNC is gaining access to much of the breeder reprocessing technology for oxide fuels that the United States has chosen not to use in the near term. At the same time, because of this program, the United States expects to maintain the core of expertise at ORNL and to seek out additional uses for certain U.S.-developed technologies. In particular, the remote maintenance developments in the Consolidated Fuel Reprocessing Program have provided the expertise and motivation for several robotics-related programs at ORNL that are now carried out in several divisions, including a new initiative in the Environmental Restoration and Waste Management Robotics Program, which utilizes the technology developed in the Consolidated Fuel Reprocessing Program.

The prime areas of interest in the collaboration are (1) centrifugal contactors for solvent extraction; (2) the head-end hardware systems for fuel-element disassembly with lasers, shearing, and continuous dissolution; and (3) overall support to facility concepts and design. Other technical exchanges, which are rapidly winding down because of limited funding, continue in (1) a comparison study of the fuel-cycle facility concepts with the United Kingdom, (2) a rad-hardening of signal-transmission systems with France, and (3) a "hot" demonstration of centrifugal contactors in the U.K. Dounreay fast-breeder reprocessing plant. The R&D for the rad-hardening program was completed in FY 1990. The program will continue with design and data reviews through FY 1992 in order for the United States to obtain operational data from the demonstration at Marcoule. The U.S. contactors for the Dounreay demonstration were provided in FY 1989. Most of the remainder of the program, to be carried out over the next 5 years, will be completed by the U.K. staff, with ORNL participation consisting only of review and short-term visits for obtaining operating data.

Transfer of technology to a U.S. firm for the Advanced Servomanipulator has been accomplished, but commercial availability awaits the identification of a specific use. Initial use could be in the ORNL Waste Handling and Packaging Plant, with other opportunities possible in other U.S. waste-management programs and in facilities in Japan and Germany. Broader use of centrifugal contactors is being sought in other DOE facilities and industry for reprocessing and other specialty recovery and process applications. Contactors have been provided to DOE sites at the Y-12 Plant and in Idaho. These activities hopefully will lead to opportunities to support future DOE fuel-cycle facilities as the needs for such become better known.

Commercial Reactor Programs Improved safety, performance, and availability for LWRs is an important national need. Responsibility for the evolution of LWR designs is primarily in the hands of industry, although DOE still funds design-certification and review tasks. ORNL's involvement in LWR development is primarily in the role of design reviews, cost studies, and development of specialized technologies such as passive design features and improved controls systems.

The DOE LMR program is shifting emphasis from breeding fissile fuel to actinide recycle. ORNL supports both the reactor design and fuel-cycle development portions of the LMR program. ORNL support to DOE for this new actinide recycle initiative includes development and assessment of program plans and recommendations concerning chemical, engineering and licensing issues. DOE anticipates that this program will grow substantially in the near future and expects ORNL experience and capabilities to make significant contributions. In the LMR program ORNL's tasks include advanced controls development, materials development and testing, reliability data base management, robotics, and design review and analysis tasks. Several of the tasks are cosponsored by organizations in Japan.

Primary emphasis in the national high-temperature gas-cooled reactor (HTGR) program is on development of a modular HTGR

(MHTGR) using steel pressure vessels for the reactor core and steam generators in a side-by-side arrangement. ORNL has lead responsibility for the HTGR Base Technology Development Program. Cost-reduction studies by vendor and utility organizations currently in progress may produce some changes to the technology needs to support design. ORNL's role in the program remains technology development in the areas of fuel development, fission-product behavior, graphite and metals testing, safety studies, and shielding methods validation. ORNL expects to continue involvement in technology development for the MHTGR until final design is complete

New Initiative—Actinide Burning

The DOE is undertaking a reexamination of actinide burning beginning in FY 1991 to examine the potential for assisting the geologic repository program and fostering the long-term future of nuclear power. Prior work over the past 15 years at ORNL in breeder fuel cycles, and in the earlier major assessment of actinide burning, places ORNL in a strong position to become a major participant in this program. Preliminary work in support of DOE's planning activity was done in FY 1990.

"Actinide burning" is a term applied to an advanced nuclear fuel cycle in which a high percentage of the actinides are recovered from spent nuclear fuel and used as fuel in fast reactors, where they are ultimately fissioned. This concept extends the conventional concept for coupling light-water reactor (LWR) and LMR fuel cycles by including recovery and recycle of essentially all of the minor actinides (americium, curium, and neptunium) in addition to plutonium. The purpose is to remove those long-lived actinides and, thus, reduce the long-term hazards in a geologic repository. Actinide burning has the potential to reduce the repository hazards issues from a million-year to a thousand-year time frame. This may increase public acceptance of the high-level waste (HLW) repository while providing some potential to reduce costs by facilitating licensing and decreasing the need for site characterization. Implementation of such a plan would represent a very major change from current policies of spent fuel disposal, and the best expertise in the country is needed to address the many relevant technical and institutional issues.

ORNL is seeking a major role in this program because of its broad base of expertise. This background includes development of aqueous reprocessing for LWR and LMR spent fuels, substantial and diverse involvement with the repository programs, broad capabilities in fuel-cycle systems analysis and economics, and the related important issues of safeguards and nonproliferation.

ORNL envisions a major role including technical development and some form of program integration or technical support role to DOE in planning and managing the national program. Support will also be provided in related waste-management and regulatory interactions, including overall nuclear fuel-cycle systems studies (Table 31).

Table 31. Budget projections for actinide burning
($ in millions)

1990	1991	1992	1993	1994	1995	1996
0.05	1.0	1.5	2.0	3.0	3.0	3.0

and a final safety analysis report has been reviewed by the Nuclear Regulatory Commission (NRC). The date when this will occur depends on the level of DOE funding for design and technology development, and on whether a first order is placed. Current estimates for completion of technology development are 1997 to 2000.

Space and Defense Energy Systems In the area of space nuclear power, ORNL continued technical support for the development and fabrication of isotopic-powered and fission reactor power systems. For space missions and terrestrial applications that use heat generated by isotopic power devices, the primary emphasis is on development of improved materials. Activities include the production of iridium alloy clad-vent sets to contain heat-generating radioisotopes and carbon-bonded carbon-fiber thermal insulators capable of effective operation at 1300°C. Production of these materials began in FY 1990 and is anticipated to continue through 1993 in support of NASA's comet rendezvous asteroid flyby and Cassini missions. In preparation of this important production activity, ORNL performed an operational readiness review to ensure that all activities associated with the production tasks are in compliance with appropriate health, safety, environmental, and quality requirements.

ORNL will continue in its role in the development and characterization of high-temperature materials and components for fission reactor concepts providing electrical power in the hundreds-of-kilowatt range, (the SP-100 Project). In the ground engineering systems phase of the SP-100 Project, ORNL continues to have a significant role in the testing and evaluation of high-temperature materials. In addition, work was initiated in FY 1988 to characterize materials for nuclear-shield fabrication and the optimization of a diverse high-temperature sensor. Prototypes of the temperature sensor and the nuclear shield will be fabricated for subsequent testing in the nuclear assembly test to be performed at Hanford, Washington, in FY 1995.

The multi-megawatt space power program, for which ORNL has been conducting materials research since 1984, has been cancelled.

Nuclear Propulsion for Space Exploration Initiative

The Bush administration announced a new space initiative in July 1989. This initiative focuses on colonization of the moon and a manned expedition to Mars. The success of the Space Exploration Initiative (SEI) will probably depend upon the use of nuclear propulsion. An extensive SEI planning effort will occur during the last part of FY 1990 and will continue through FY 1991. The planning effort associated with nuclear propulsion systems will likely cover the entire spectrum of concepts that have been proposed in the past (solid, liquid, and gaseous fuel; gas and liquid-metal cooling; closed and open cycle; Rankine cycle; Brayton cycle; thermionics; etc.). Many of these concepts build on technologies that have been developed by DOE multiprogram laboratories in support of the current HTGR, LMR, and SP-100 programs and the earlier Space Nuclear Auxiliary Power programs.

SEI will probably be a large effort. From FY 1991 through FY 2006, the preliminary budget estimate for the nuclear propulsion element alone is $4 billion. The broad objectives of SEI include space stations, manned colonies on the moon, and travel to Mars by the year 2019. The near-term focus of SEI will be technology development, including the following:

- searching for innovative approaches and technologies;
- investing in high leverage, innovative technologies with potential to make a major impact on cost, schedule, and performance; and
- maintaining mission, concept, and systems analysis studies.

An Exploration Technology Program (ETP) has been established under the National Aeronautics and Space Administration (NASA) to develop a broad set of technologies to support SEI. ETP is organized into eight technology areas: space transportation, in-space operations, surface operations, human support, Lunar and Mars science, information systems, automation, and nuclear propulsion.

ORNL's major interest is nuclear propulsion. The focus of nuclear propulsion technology development will include both nuclear thermal propulsion (NTP) and nuclear electric propulsion (NEP). NTP systems must be capable of long life and multiple starts and will probably be based on enhancements of the NERVA/ROVER experience of the 1960s. NEP systems will feature both high-power, long-life electric thrusters and advanced, low-mass radiator and power-management systems similar to the SP-100 reactor to provide hotel power for space and terrestrial stations.

ORNL's approach to SEI planning will be to identify areas in which the Laboratory can contribute. This will involve reviewing past work on nuclear propulsion for space applications and approaches being discussed for the future. We will inventory facilities, equipment, and personnel assets in those areas and develop specific proposals (scope, schedule, and cost estimates) for deployment of assets to provide data and demonstrate feasibility to support the first phase of SEI nuclear propulsion development. We will contribute to the development of task plans for technical areas listed in the SEI program plan and try to enhance perception within the technical community regarding ORNL's expertise and credentials by organizing and hosting technical workshops. Budget projections are given in Table 32.

Table 32. Budget projections (BA) by fiscal year for the Nuclear Propulsion for Space Exploration Initiative ($ in millions)

1990	1991	1992	1993	1994	1995	1996
0	1.0	2.0	4.0	5.0	6.0	8.0

AH—Remedial Action Program

Major activities in remedial action programs (RAPs) involve the conduct of radiological surveys on private properties near inactive mill tailings sites [Uranium Mill Tailings Remedial Action Project (UMTRAP)] and at facilities formerly used under contract with the Atomic Energy Commission [Formerly Utilized Sites Remedial Action Project (FUSRAP)]. Identification, characterization, and verification of the current radiological status of sites involved in DOE's RAPs are performed to provide a basis for the reduction of health impacts of fuel cycle activities. To perform its activities in a cost-effective manner, ORNL maintains an office in Grand Junction, Colorado, at the request of DOE. Advancing state-of-the-art equipment and methodologies are an integral part of this work (Fig. 34). The ORNL Grand Junction Facility is leading the effort in identifying and recommending inclusion of various properties in the vicinity of 24 inactive uranium mill sites in UMTRAP. Additionally, the Grand Junction Facility is responsible for verifying the adequacy of remedial action taken at those sites in excess of relevant EPA criteria and DOE guidelines in UMTRAP and the western sites in the Surplus Facilities Management Project

Fig. 34. Terrain-conductivity survey is being conducted using the Ultrasonic Ranging and Data System developed by ORNL.

(SFMP). ORNL survey efforts will be reduced sharply in UMTRAP in FY 1991, when nearly all inclusion surveys will be completed.

The Oak Ridge ORNL-based group, which has functions equivalent to the ORNL group at the Grand Junction Facility, performs identification, designation, and verification activities at the radiologically contaminated sites in the FUSRAP and eastern SFMP sites. FUSRAP funding is expected to remain level for FY 1991 through 1995. SFMP funding, on the other hand, is expected to increase significantly as the amount of decommissioning efforts at federal facilities increases. The SFMP and the Defense Decontamination and Decommissioning Projects provide (1) maintenance and surveillance to assure the safety of DOE facilities awaiting decommissioning, (2) planning for the orderly decommissioning of facilities, and (3) implementation of a program to accomplish disposition of all facilities. ORNL will provide verification that these facilities are decontaminated within established DOE guidelines.

CD—Uranium Enrichment

Applying technology derived from DOE programs in Uranium Enrichment (UE) is an increasing and important contribution by ORNL to solving problems of national importance. The Applied Technology Division (ATD) was given the charter by DOE-UE to use uranium-enrichment-derived technology to support DOE, other federal and state agencies, and the private sector. This technology provides significant new ORNL strengths in the following areas of science and technology:

- advanced polymeric composite materials;
- advanced manufacturing, prototyping, and characterization of engineered materials;

- structural design and analyses, fluid flow, and mechanics;
- laser and fiber-optic systems;
- remote measurements data and imaging systems;
- power electronics;
- lightweight, high-power motors;
- uranium and toxic-material handling and decontamination; and
- centrifuge separations.

The ATD capabilities include significant expertise that is both unique and synergistic with other ORNL resources. In such areas as organic matrix composite materials and lightweight, high-energy-density motors and generators, ATD provides both national and international technology leadership. Currently, ATD has over 40 sponsors from DOE, Department of Defense (DOD), and the private sector; most of ATD's funding is provided by DOE.

Current specific DOE applications include composite materials R&D for defense programs and energy research. ATD also transfers technology to the DOD and to state and private-sector sponsors. The transfer is in the form of licensable intellectual property, reports, prototypes, and workshops. Two composite materials workshops attracted over 500 people in 1989 and are expected to attract at least that number in the next workshop, scheduled for 1991.

ATD also has the DOE-uranium enrichment mission of closing out the Gas Centrifuge Program. Termination of the Gas Centrifuge Program started in FY 1985. It includes environmental restoration of the 400,000 ft^2 of former centrifuge facilities located on the K-25 site, at the Applied Technology Facility, through facility decontamination and cleanup, hazardous materials storage and disposal, centrifuge workers health studies, gas centrifuge enrichment plant claims settlement, and disposition of materials and equipment. The facilities decontamination and cleanup started in FY 1988. At the end of FY 1990, approximately 35% of the former centrifuge facilities have been put to new use for the benefit of DOE. Divisions now occupying and utilizing the space include ORNL's Energy Division and several K-25, Y-12, or Martin Marietta Energy Systems divisions (Environmental Restoration, Y-12 Development Division, Computing and Telecommunications Division, Technical Division, International Technology Division, and Fabrication and Maintenance Division). The remainder of the space, about 270,000 ft^2, is under surveillance and maintenance.

The FY 1990 UE budget request of $3.2 million to continue the facilities environmental restoration (decontamination and cleanout) was reprogrammed in order to address environmental problems at the Portsmouth Gaseous Diffusion Plant. The impact of the reprogramming is a 1-year delay in cleaning and decontamination of the former centrifuge facilities.

The combination of a uranium enrichment mission to complete the activities associated with the termination of the centrifuge program and the charter to make the enrichment-based technologies available for DOE, other state and federal agencies, and the private sector affords a unique opportunity for ORNL to enhance its reputation as a national materials technology resource and its reputation for technology applications. Significant initiatives within this mission include

- an organic matrix composites initiative with UT;
- the application of system-engineering modeling and risk-analysis techniques to support critical facility operating and safety systems;
- the application of advanced power and electronic control and machinery technology to support motor and generator development;
- the development of a motor concept that capitalizes on superconducting materials technology to provide a lightweight, high-power motor or generator (a collaborative effort of ATD, Energy, and Fusion Energy divisions);
- the application of unique electro-optic measurements and data-recovery systems for noncontact (or remote) and nonintrusive measurements in hazardous environments over temperatures ranging from cryogenic temperatures to 1400°C; and
- the use of facilities formally used by the gas

centrifuge program for the environmental restoration program and the use of restored facilities for expanded programs by ATD and other ORNL divisions.

Non-ATD based CD work at ORNL is composed of a collection of on-call assignments related to cost studies, economic analysis, information management, and standards development. In each case, the CD support makes up a modest fraction of the total support at ORNL for this work.

ST—Isotopes

The Isotopes Program is essential for production of both stable and radioactive isotopes used in medical applications, basic research, and industry. Performing isotope separations in the calutron facility, ORNL continues to be the only free-world source of enriched isotopes of thallium, zinc, tellurium, and calcium. These isotopes are vital to the medical community, where they are used for diagnostic and clinical procedures. Other calutron isotope products are used nationally and internationally to study the basic physics of the nucleus. Through its specialized radiochemical processing facilities, the Isotopes Program also has been providing researchers and industry with special preparations of tritium and fission products such as ^{85}Kr. With successful achievement of the HFIR restart, the production of other research and medical radioisotopes may be resumed.

The program was established under a revolving fund concept with an initial capitalization that was too small to accommodate all the immediate needs of the program. As a result, a decision was made to move most of ORNL's responsibilities for radioisotope products and services (i.e., those that required processing in the Isotopes Circle facilities) from ORNL to other sites. A brief hiatus in stable-isotopes enrichment was experienced, but these operations in the calutrons will resume and expand.

The future role in production of radioisotopes in HFIR will require identification of suitable processing facilities at ORNL.

Office of New Production Reactors

This program was first described as part of the MHTGR initiative in the FY 1990–1995 *Institutional Plan* (Table 33). During FY 1989, ORNL and the other national laboratories assisted the Office of New Production Reactors in development of 5-year technology development plans (TDPs). [TDPs were later renamed engineering development plans (EDPs).] In FY 1990 ORNL performed work in areas specified in the EDP, while the design organizations produced two conceptual designs for the heavy-water reactor (HWR); one has been selected to go forward into preliminary design. A conceptual design has also been produced for the MHTGR. During the fourth quarter of FY 1990, DOE, the laboratories, and the design organizations have refined the EDP to incorporate

Table 33. Office of New Production Reactors major program summary
[$ in millions—budget authorization (BA)[a]]

Budget and reporting code	Major program	Fiscal year			
		1989	1990	1991	1992
NP	New Production Reactors	NA	16.9	15.0	8.1
Percentage of total Laboratory funding—BA		NA	3.3	2.2	1.1

[a]Figures include operating BA, capital equipment, and construction, if any.

information developed during the conceptual-design phase.

In FY 1991 work will proceed according to the EDPs (as amended). Responsibility for management of EDP work will be transferred for the most part from DOE headquarters to the field [i.e., to the project offices of the management and operations (M&O) contractor]. HWR technology development will be managed through the Westinghouse Savannah River Company, and MHTGR work will be managed through EG&G Idaho. Selected EDP areas will still be managed by the Office of New Production Reactors from Washington. The decentralization in management is driven by the knowledge that the field project offices will be responsible for oversight of preliminary and final design, supervision of construction, and operation of the plants once they are built. The technical experience needed to perform these tasks will be developed through oversight of the technology development and design tasks over the next few years. It is anticipated that in FY 1991 most of the work performed at laboratories outside the Westinghouse Savannah River Company and EG&G Idaho will continue to be performed there, but more of the work will be retained by the Westinghouse Savannah River Company and the Idaho National Engineering Laboratory in the out years. ORNL involvement in the New Production Reactor program will end in 1995 or 1996 if current schedules for design are followed.

Office of Civilian Radioactive Waste Management

ORNL's work for the DOE Office of Civilian Radioactive Waste Management (OCRWM) is conducted under Program DB. ORNL's DB activities currently involve the geologic repository (DB01), transportation and system integration (DB04), and program management and technical support (DB05). Overall, work in Program DB is expected to remain stable or grow modestly (Table 34).

DB—Nuclear Waste Fund

The repository component of the OCRWM program, which supports the ongoing geotechnical activities in support of the Yucca Mountain Project, was significantly reduced after FY 1989, with further reductions anticipated in FY 1990 and 1991. Current work primarily consists of performing technical reviews and evaluations of various Yucca Mountain Project reports. No work in this area is anticipated in FY 1992 and beyond.

The transportation and system-integration component of the program supports three activities at ORNL. The first is the Waste Systems Data and Development (WSDD) project, which is charged with developing data bases; technology models; and waste-acceptance criteria, and with

Table 34. Office of Civilian Radioactive Waste Management major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1989	1990	1991	1992
DB	Nuclear Waste Fund	10.3	7.1	11.4	14.3
Percentage of total Laboratory funding—BA		2.2	1.4	1.7	2.0

[a]Figures include operating BA, capital equipment, and construction, if any.

assessing and enhancing technical computer codes. The WSDD activities are concentrated on data, calculational techniques, and modeling common to the major components of the DOE-OCRWM waste-management system; these activities assist OCRWM in performing design and trade-off studies required for the establishment and operation of an integrated, efficient, high-level nuclear waste-management system. A new initiative is expected in support of work by Lawrence Livermore National Laboratory in their design of the waste package for the repository.

Under the second activity, ORNL provides technical support and undertakes specific technical work related to the DOE-Chicago Operations Office's lead responsibility for the OCRWM Transportation Operations Program. The third activity involves providing analytical, experimental, and testing support to the parts of OCRWM's transportation program concerned with cask development and the institutional and economic aspects of transportation. In support of this activity, ORNL is performing numerous tasks related to the development of shipping casks and the supporting transportation system infrastructure. Current work areas include evaluating transportation routes and preparing maps of these routes, assessing the acceptability of casks and related documents, and evaluating the drop-testing capabilities of the Tower Shielding Facility as a first step in developing a comprehensive cask-testing facility. Work in all three areas of transportation and systems integration is expected to remain stable or grow modestly.

The program-management and technical-support component of OCRWM supports a major portion of the Integrated Data Base Project and the review and evaluation of the environmental aspects of key OCRWM documents. Support in this area is expected to remain stable.

Assistant Secretary for Defense Programs

Programs sponsored by the Assistant Secretary for Defense Programs include Weapons Activities, Safeguards and Security, Materials Production, and Defense Waste and Transportation Management (Table 35).

GB—Weapons Activities

A variety of tasks and projects are supported by Program GB, including some support provided

Table 35. Assistant Secretary for Defense programs major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1989	1990	1991	1992
GB	Weapons Activities	1.7	1.9	0.7	0.3
GD	Nuclear Safeguards and Security	0.7	0.7	0.7	0.7
GE	Materials Production	7.7	5.5	6.1	9.1
GF	Defense Waste and Environmental Restoration	30.8	33.9	43.3	54.1
Total		40.9	42.0	50.8	64.2
Percentage of total Laboratory funding—BA		8.6	8.2	7.5	8.8

[a]Figures include operating BA, capital equipment, and construction if any.

to the Radiation Shielding Information Center, the development and maintenance of a cost-risk analysis methodology for nuclear weapons production, the development and maintenance of state-of-the-art analytical methods used to analyze transportation packages, and technical program assistance for the New Production Reactor Program.

Program GB is also supporting one-half of the costs for the Mark 42 Processing Program for FY 1990 at $1.5 million. This program was initiated in FY 1989 to recover and purify about 75 g/year of ^{243}Am and about 15 g/year of ^{244}Cm for use in weapons diagnostics at Los Alamos National Laboratory and Lawrence Livermore National Laboratory. Large quantities of these materials are available at the Savannah River site in the form of irradiated target assemblies (Mark 42 targets) and raffinate solutions. The targets can be processed to recover the actinide elements at the ORNL REDC.

GD—Safeguards and Security

This activity, begun in 1985, involves two projects: (1) the detection of high explosives in real time by the technique of mass spectrometry/mass spectrometry (MS/MS), and (2) independent fissile inventory-verification and tank-calibration techniques by mass spectrometry. Both efforts are to remain relatively constant, although the first task could accelerate if a major breakthrough is achieved.

The MS/MS technique has been demonstrated to be a powerful analytical method to analyze complex mixtures for targeted compounds. It thus has potentially direct applicability to the detection of vapors from high explosives. A very sensitive, small high-explosive vapor detector is under development. A laboratory prototype was designed and constructed and is undergoing field testing.

GE—Materials Production

This program includes the Mark 42 Processing Program, the ^{252}Cf Industrial Sales/Loans Program, and the ^{233}U Storage and Distribution Program.

For FY 1990, the costs for the Mark 42 Processing Program were divided between programs GE and GB, for a total funding of $3 million. Beginning in FY 1991, the entire costs for the program are expected to be provided by Program GE. The Mark 42 Processing Program involves the recovery and purification of ^{242}Pu, ^{243}Am, and ^{244}Cm from irradiated targets from the Savannah River site. These materials are to be used in weapons diagnostics at Los Alamos and Lawrence Livermore national laboratories. The irradiated targets are shipped to Battelle Pacific Northwest Laboratories for disassembly, and then the pieces are processed in the REDC. One Mark 42 target will be processed each year. Processing of the first Mark 42 target began in FY 1990. The funding supplements the Transuranium Element Processing Program funds at the REDC. Because massive funding for restart of the Multipurpose Plutonium Processing Facility at Savannah River is unlikely, the Mark 42 program at ORNL should continue for a number of years.

Other activities conducted under Program GE include the ^{252}Cf Industrial Sales/Loans Program and the ^{233}U Storage and Distribution Program. The ^{252}Cf Industrial Sales/Loans program continues to supply ^{252}Cf and to fabricate neutron sources for medical, research, and industrial uses. Facilities for purification of ^{233}U, located in the Radiochemical Processing Plant (RPP) at ORNL, were placed in standby condition in 1989. Safeguarded storage of ^{233}U in the RPP is being continued. A conceptual design is available for installing new ^{233}U processing facilities with significantly improved capabilities if DOE's needs for purification of ^{233}U are renewed. The new facilities would be located in two of the shielded cells at the REDC.

GF—Defense Waste and Transportation Management

Funding within this programmatic area is being consolidated under the Assistant Secretary for Environmental Restoration and Waste

Management; however, the consolidation is still in progress. For this reason, the prior programmatic title has been retained.

ORNL performs research, development, and demonstration activities for the GF program on radioactive, mixed, and hazardous wastes through the Office of Technology Development of the Office of Environmental Restoration and Waste Management. Examples of R&D projects include (1) development of accurate field analytical instrumentation; (2) bioremediation of polychlorinated biphenyls (PCBs), trichloroethylene (TCE), and other hazardous organic materials; (3) use of robotics to enhance the safety and to minimize exposure of environmental restoration personnel; (4) development of methods for the treatment of mixed wastes; (5) removal of toxic metals from contaminated scrap; and (6) substitution of chlorinated hydrocarbons as cleaning agents. Demonstrations supported under this program include methods for removing volatile organic carbons from groundwater, the removal of acidic-gas and heavy-metal emissions from incinerators, the chemical destruction of PCBs in mixed waste, and in situ grouting and vitrification to stabilize toxic materials. This area is expected to grow significantly over the next few years as DOE expands its efforts to address waste management issues at Defense Program facilities.

ORNL created an Environmental Restoration and Facilities Upgrade Program in 1985 to improve waste management and environmental restoration, enhance regulatory compliance capabilities, and provide comprehensive long-range planning. The first annual *ORNL Long-Range Environmental and Waste Management Plan* was issued in December 1985. The ORNL Waste Management operating expense budget has about doubled every two years since 1985. This rapid buildup must continue in order to meet our responsibility of bringing ORNL facilities and operations into compliance with applicable environmental, safety, and health standards consistent with the DOE-Environmental Restoration and Waste Management Five Year Plan. It is recognized that this rapid buildup requires skillful management to effectively scope, schedule, and estimate resources for projects to assure that they meet the program's objectives. Lessons have been learned from experiences where DOE projects have proceeded without adequate testing and evaluation.

ORNL projects result from a structured process of strategic planning; an understanding of the fundamental processes; adherence to the NEPA process and other laws, regulations, and standards; quarterly interface meetings with regulatory officials; application of project management experience; and where available experienced private industry performs studies and conducts demonstrations to ensure a viable design before proceeding. Recent enhancements to our overall waste management planning process includes organizational changes at the DOE Oak Ridge Operations, Martin Marietta Energy Systems, and ORNL; expanded use of private industry; emphasis on DOE-wide lessons learned; and multisite-multiplant efficiencies. We are committed to continue this pursuit of excellence on ORNL projects and activities.

ORNL activities for DOE encompass management of LLW and transuranic (TRU) wastes as well as ORNL site remedial actions.

Both solid and liquid LLWs are generated at ORNL. The overall solid LLW management strategy includes waste reduction through improved operations in existing facilities; volume reduction by supercompaction; interim storage; demonstration of waste treatment and disposal techniques expected to be suitable for a new disposal facility; and the Interim Waste Management Facility (IWMF), which will be operational by 1992. Storage and disposal techniques for providing greater confinement are used for all solid LLW. A tumulus-based demonstration is nearing completion and a second tumulus disposal area has been constructed. Performance of the tumulus will be evaluated by multiyear sampling of liquid taken from the tumulus pad and the underpad collection system and groundwater-monitoring wells. Additional tumuli are planned as part of the IWMF.

Disposal of concentrated liquid LLW at ORNL by hydrofracture in shale deposits was suspended in 1984, and this waste has accumulated

since that time in doubly contained storage tanks. The limited storage capacity is essentially full, and operational flexibility of the liquid LLW system is significantly impaired, threatening ORNL's ability to continue the R&D that generates liquid LLW. A general strategy has been developed for dealing with liquid LLW. The strategy consists of the following elements.

- Execution of additional emergency avoidance solidification campaigns for solidifying liquid LLW as cement-based waste will be carried out in increments of about 50,000 gal (~189,000 L). This solidified waste will be stored at ORNL pending further evaluation of disposal options. This operation will restore some operational flexibility to the liquid LLW system.
- Implementation of in-tank evaporation in the storage tanks for removal of about 150,000 gal of water during the next 5 to 8 years. Initial testing of this approach has been completed satisfactorily, and operation was initiated during FY 1990.
- Processing in the Waste Handling and Packaging Plant (WHPP) to convert TRU sludges and associated liquid waste currently in the storage tanks to a solid, remotely handled (RH) TRU waste that will be disposed of in the Waste Isolation Pilot Plant (WIPP) located near Carlsbad, New Mexico. This will remove most of the current waste inventory from the storage tanks.
- Development of long-term treatment capabilities that will allow production of waste from future newly generated liquid LLW that can be disposed of on the Oak Ridge Reservation.

ORNL deals with two types of TRU waste: contact handled (CH) and RH. TRU waste will ultimately be shipped to WIPP; however, waste to be sent to WIPP must be certified as having met the WIPP waste acceptance criteria. ORNL received approval for certification of newly generated (NG) CH TRU waste in June 1986, and all NG CH TRU waste has been examined from the standpoint of certification since that time. CH TRU waste is packaged in stainless steel 55-gal drums. The drums are examined by neutron interrogation, segmented gamma scan, and X rays. ORNL completed examination of its stored CH TRU waste, and about 50% of the drums met the certification requirements; however, there have been subsequent changes in the certification requirements. Further work will be necessary before all of the drums can be certified. New certification requirements associated with the transportation of the waste to WIPP must also be met.

ORNL continues to generate limited quantities of solid RH TRU waste. Most of the waste of this type within DOE (about 1000 m^3) is stored at ORNL in large concrete casks that are unsuitable for shipment to WIPP. These wastes will be repackaged in containers that meet the requirements of the U.S. Department of Transportation (DOT) and will be certified to meet WIPP waste acceptance criteria. In addition to the solid RH TRU waste, the ORNL liquid LLW storage tanks contain about 250,000 gal of RH TRU sludges that must be solidified and certified before shipment. A major facility, the WHPP, is proposed as an FY 1994 ORNL line-item project. The facility will allow repackaging contents of the concrete casks, solidifying the sludges, and certifying the resulting RH TRU waste.

Past R&D and waste-management activities at ORNL have produced a significant number of surplus, inactive facilities that are contaminated with low-level radioactive and/or hazardous chemical wastes, as well as off-site contamination. Such sites include solid waste storage areas (SWSAs), waste ponds, and seepage pits; radwaste processing and transfer facilities; research laboratories; dedicated environmental research areas; experimental reactors; radioisotope development facilities; the areas surrounding these sites; and off-site contamination in the Clinch and Tennessee rivers. Over the past several years, significant environmental legislation has been enacted at both the state and federal levels to provide controls over facility discharges and cleanup of contaminated sites. Of particular significance to ORNL are not only specific

requirements for landfills (e.g., affecting SWSA 6) and underground storage tanks but also the more general requirements for assessment and corrective actions at sites found to be sources of continuing contaminant releases to the environment.

Implementation of remedial actions at ORNL began with identification of sites requiring corrective action and will end with final certification of site closure or decommissioning activities. Between these two points is a structured path of program planning, site characterizations, alternatives assessments, technology demonstrations, maintenance and surveillance, and necessary interim corrective actions. Accomplishment of these activities will extend over several years. The path and timing for a given site will be dependent on a number of variables including site characteristics, regulatory requirements, and funding availability.

Current remedial action activities center on (1) a comprehensive remedial investigations/feasibility study for characterizing SWSA 6 and evaluating the resulting data, (2) interim closure of the Resource Conservation and Recovery Act (RCRA) storage units within SWSA 6, (3) planning and technology demonstration for underground tank closure, and (4) maintenance and surveillance of inactive facilities.

Assistant Secretary for Conservation and Renewable Energy

ORNL conducts research and provides field management on a wide range of programs for the Assistant Secretary for Conservation and Renewable Energy (CE) (Table 36). Ultimate goals are to increase energy efficiency and the use of renewable resources, which would help increase our industrial competitiveness, reduce our dependence on oil imports, and reduce the cost of energy to consumers.

Table 36. Assistant Secretary for Conservation and Renewable Energy major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1989	1990	1991	1992
AK	Electric Energy Systems	4.6	4.4	10.0	10.5
AL	Energy Storage Systems	1.0	0.4	1.6	1.7
CE	Hydropower	*b*	0.2	0.6	0.4
EB	Solar Energy	2.9	3.5	5.2	9.1
EC	Building and Community Services	10.2	9.5	10.9	13.2
ED	Industrial Energy Conservation	2.3	2.0	2.5	3.1
EE	Transportation	20.2	21.4	23.1	23.2
EF	State and Local Programs	0.2	1.8	2.0	1.9
EG	Multisector	5.4	6.1	5.7	7.4
Total		46.8	49.3	61.6	70.5
Percentage of total Laboratory funding—BA		9.8	9.7	9.4	9.7

[a]Figures include operating BA, capital equipment, and construction, if any.
[b]Less than $0.1 million.

Particular effort is made to ensure that the research is responsive to industry needs and that research results are made known to industry in a form that will encourage immediate use. Operation of two Conservation Program user facilities, the High Temperature Materials Laboratory (HTML) and the Roof Research Center, has been a key element in interactions with industry.

Two ORNL continuing initiatives, High-Temperature Superconductor Research and Development and Energy Technologies for Developing and Eastern European Countries, seek funding from DOE-CE programs. In both of these ORNL is continuing to seek expanded support for research believed to be especially important to future industrial competitiveness.

Noteworthy changes in expected funding levels during the planning period are the following. Increased funding for Program AK reflects increased requirements for high-temperature superconductivity. Increased interest in environmental advantages of biomass may result in higher funding for Program EB. Increased funding is predicted for Program ED in expectation that the metals initiative, the continuous fiber ceramic composites initiative, and other ceramics development will entail increased activity. A substantial increase in Program EF will result from the ORNL assignment for evaluation of the Weatherization Assistance Program. Additional funds are also proposed for the ORNL initiative, Energy Technologies for Developing and Eastern European Countries.

AK—Electric Energy Systems

Scientific breakthroughs in high-temperature superconductors have provided a challenge to the scientific community to develop enabling technologies for electrical conductors used in many commercial applications. At the same time, the need to find more effective mechanisms for government and industry to work together was recognized. These two needs have led to the creation of High-Temperature Superconductivity Pilot Centers at ORNL, the Los Alamos National Laboratory, and Argonne National Laboratory. The ORNL pilot center is establishing cooperative research projects with industrial firms to develop high-temperature superconductivity to a commercial technology. To expedite and encourage the formulation of cooperative projects, DOE has established a novel set of business arrangements. The agreements regarding ownership of intellectual property are flexible, additional safeguards have been put in place for the protection of proprietary data, and a simplified model cooperative agreement is being used. These arrangements have stimulated intense industrial interest. Several cooperative projects with leaders in superconducting technology have been started, and formulation of additional projects is limited only by availability of DOE funds.

By the end of July 1990, 16 cooperative agreements had been signed, providing for ORNL researchers to work with a wide variety of large companies, small businesses, and universities that are in the vanguard of superconductivity development. Under a cooperative agreement with American Superconductor Corporation, a bismuth oxide wire was fabricated which achieved noteworthy combination of current density and magnetic field at relatively low temperatures (Fig. 35). In another agreement with Westinghouse and the University of New Hampshire, an aerosol pyrolysis process was developed for synthesizing phase-pure submicron Y-123 powders. The powders proved to have higher current densities than samples from commercially available powders.

A second, closely related project is ORNL participation in the Superconducting Technology for Electric Power Systems Program. This program seeks to develop the technology for large-scale applications requiring high current in magnetic fields, with immediate focus on the development of practical high-temperature superconductors. The ORNL project is determining the effects of processing variables on grain-boundary resistance and also investigating sintering of fine homogeneous powder made by freeze-drying and spray-pyrolysis.

In other Electric Energy Systems work during FY 1990, ORNL successfully organized a joint initiative to investigate detection techniques for

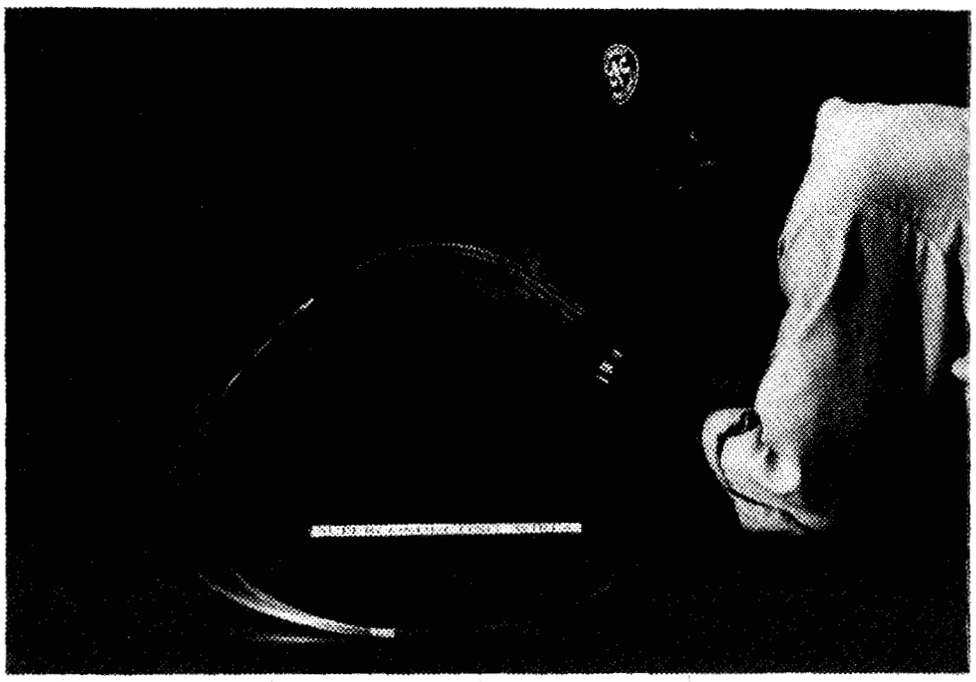


Fig. 35. Significant progress is being made on the fabrication of high-current conductors in our cooperative agreements with industry. For example, in our joint work with American Superconductor, Inc., a 60-ft length of $Bi_2Sr_2Ca_1Cu_2O_8$ (BSCCO) high-temperature-superconductivity tape has been fabricated by a powder-in-silver tube technique. The critical current density (Jc) is about 10,000 A/cm^2 at 20 K in a 5-T field. We are currently discussing an expansion of our cooperative agreement to include a task on fabrication of magnets of this material for testing in the axial-gap motor test bed at ORNL.

S_2F_{10} including the Electric Power Research Institute, the Bonneville Power Administration, the Empire State Electrical Energy Research Corporation, and Ontario Hydro.

In future years the funding for application of high-temperature superconductivity (an ORNL initiative) is expected to increase substantially. Support for other activities in Electric Energy Systems may remain constant or decline.

AL—Energy Storage Systems

ORNL has been assigned responsibility for field management of Thermal Energy Storage Systems in the areas of diurnal storage and industrial processes. The three goals are to identify advanced storage concepts, to establish technical feasibility and economic promise, and to promote implementation in the private sector through technology transfer activities.

An extremely promising concept developed over the past several years consists of a composite mixture of a metallic salt and a higher-melting ceramic. Initial experimental results and economic analyses are encouraging. When sufficient funds are available, this concept will be tested in subscale size for recovery of waste heat from a brick kiln.

A number of other concepts are being developed, including development of a self-releasing, submerged ice maker; development of a direct contact ice storage system using a unique compressor; use of ammoniated salts for chill

storage; and the use of latent thermal storage in building materials for storage of solar energy.

Congressional appropriation levels for thermal storage have been sharply reduced in recent years. Indications are that the current level may be maintained for the next several years.

EB—Solar Energy

ORNL has been assigned field-management responsibility for biomass feedstock development. The goal of this work is to develop cost-competitive terrestrial energy crops for conversion to gaseous and liquid fuels. Interdisciplinary research is conducted in the fields of physiology, genetics, silviculture, and agronomy. Much of this research is subcontracted to research institutions in crop-producing regions to investigate crop production in various climates and soil conditions (Fig. 36). The program is closely coordinated with that of the Solar Energy Research Institute, where processes for conversion of biomass into liquid fuels are under development.

The two major areas of research are short-rotation woody crops and herbaceous crops. Production questions at the technical level are being addressed in a complementary manner for both areas. Feedstock linkages with specific conversion technologies are being considered to identify and develop appropriate energy qualities in the feedstocks. Priority regions and crops have been identified to focus research on the most relevant topics. Private-sector cost sharing is strongly encouraged in subcontracted research efforts.

The issue of global climate change provides an important additional incentive for the consideration of biomass as an energy source. Preliminary analyses have shown that high-intensity tree plantations could sequester a significant portion of U.S. CO_2 emissions. Alternatively, biomass could be used to meet a significant part of U.S. energy requirements without contributing to CO_2 emissions (Table 37).

Both herbaceous and woody biomass production continue to approach the economic targets of being competitive with coal as the

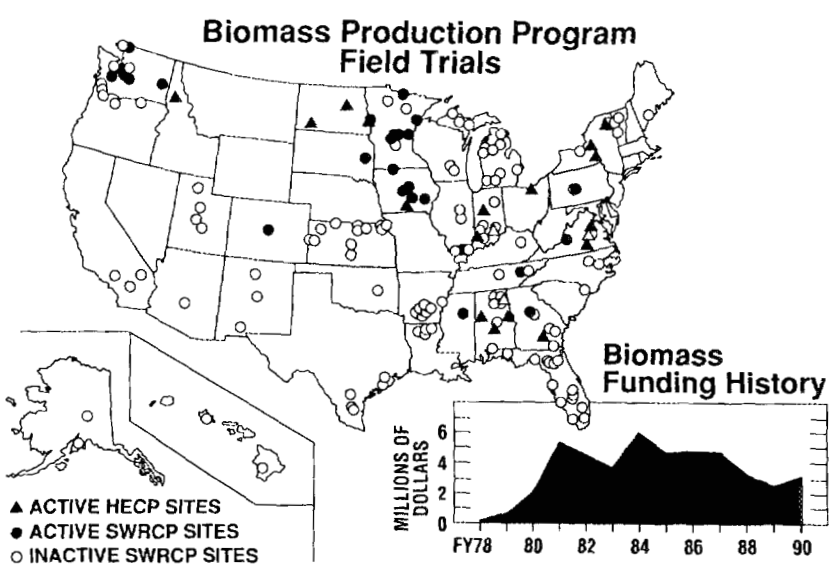


Fig. 36. Two components of the Biomass Production Program, the Short-Rotation Woody Crops Program and the Herbaceous Energy Crops Program, have selected and developed potential energy crop species under a wide range of climate and site conditions.

Table 37. SRWC energy production and carbon mitigation scenarios

	Technology status			
	Present		Advanced	
Yield (tons/acre/year)	6		10	
Land base (10^6 acres)	35		103	
Ethanol generated (10^9 gallons/year)	17.3	(12%)[a]	111.4	(79%)[a]
Electricity generated (10^{12} kWh)	0.26	(9%)[b]	2.16	(78%)[b]
Net gasoline carbon displaced (million tons C/year)	34	(3%)[c]	272	(20%)[c]
Net coal carbon displaced (million tons C/year)	67	(5%)[c]	470	(35%)[c]

[a]Percent of current U.S. gasoline consumption.
[b]Percent of current U.S. electric power production.
[c]Percent of total U.S. fossil fuel carbon emissions.

research yields more complete data on species selection and optimal cultural conditions. For instance, recent economic analysis of hybrid poplar plantations yielding 16 dry Mg/ha/yr gave production cost estimates of $17/Mg and total delivered price of chips of about $40/Mg (Fig. 37). These prices would be close to the price of coal in some parts of the country.

Research is expected to continue during the planning period with steady progress toward the ultimate goal of economic fuel production. Increasing interest in biomass as a strategy to reduce global climate change may result in higher funding levels in future years.

ORNL participation in the Solar Energy Program also includes planning activities in the Integrated Electric Utility Program for lesser-developed countries.

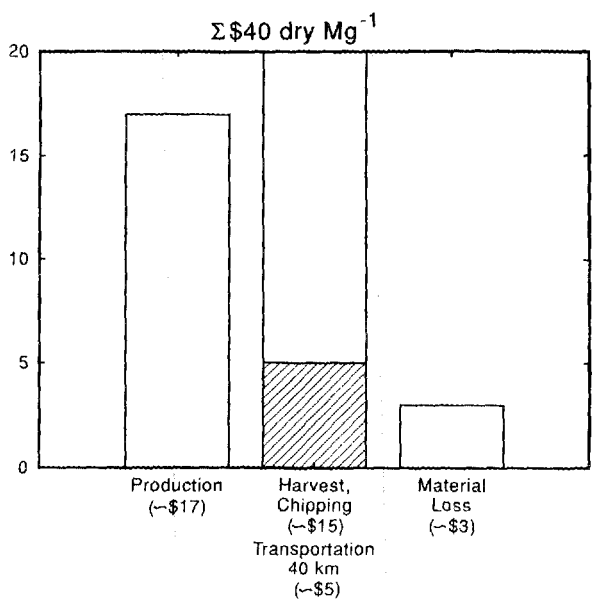


Fig. 37. The estimated total cost of producing whole-tree chips using short-rotation silviculture is currently $40/dry Mg on sites capable of producing 16 dry Mg/ha/year of harvestable biomass.

EC—Buildings and Community Systems

ORNL is responsible for field management in four project areas: Building Thermal Envelope Systems and Materials (BTESM), Existing Buildings Research, Building Equipment Research, and Building Technology Transfer.

The BTESM project seeks to identify cost-effective improvements in the design of walls, roofs, foundations, and component materials.

During FY 1990, construction was started on the Roof Mechanical Properties and Foundations

Research apparatus, which will be used to study properties of insulations manufactured with blowing agents that do not contain chlorinated fluorocarbons (CFCs). This joint DOE/industry project is more than 50% industry-funded (Fig. 38).

In Existing Buildings Research, ORNL is responsible for single-family and commercial buildings. Recent progress on modeling attic radiant-barrier performance has verified that it is now possible to predict closely the energy savings that can be obtained from such installations. Radiant-barrier insulation is emerging as a cost-effective retrofit measure, particularly when installed with conventional insulation in southern regions of the country. Increasing emphasis in Existing Buildings Research is being given to hot, humid climates. With reduced congressional funding levels, this project is able to address only the most urgent problems.

Building Equipment Research seeks to conserve energy by developing improved heat pumps for heating and cooling buildings. Both electrically driven and heat-actuated heat pumps are included. A major task in electrically driven systems is the search for acceptable substitutes for CFCs as working fluids. The international agreement (the "Montreal Accord") to limit

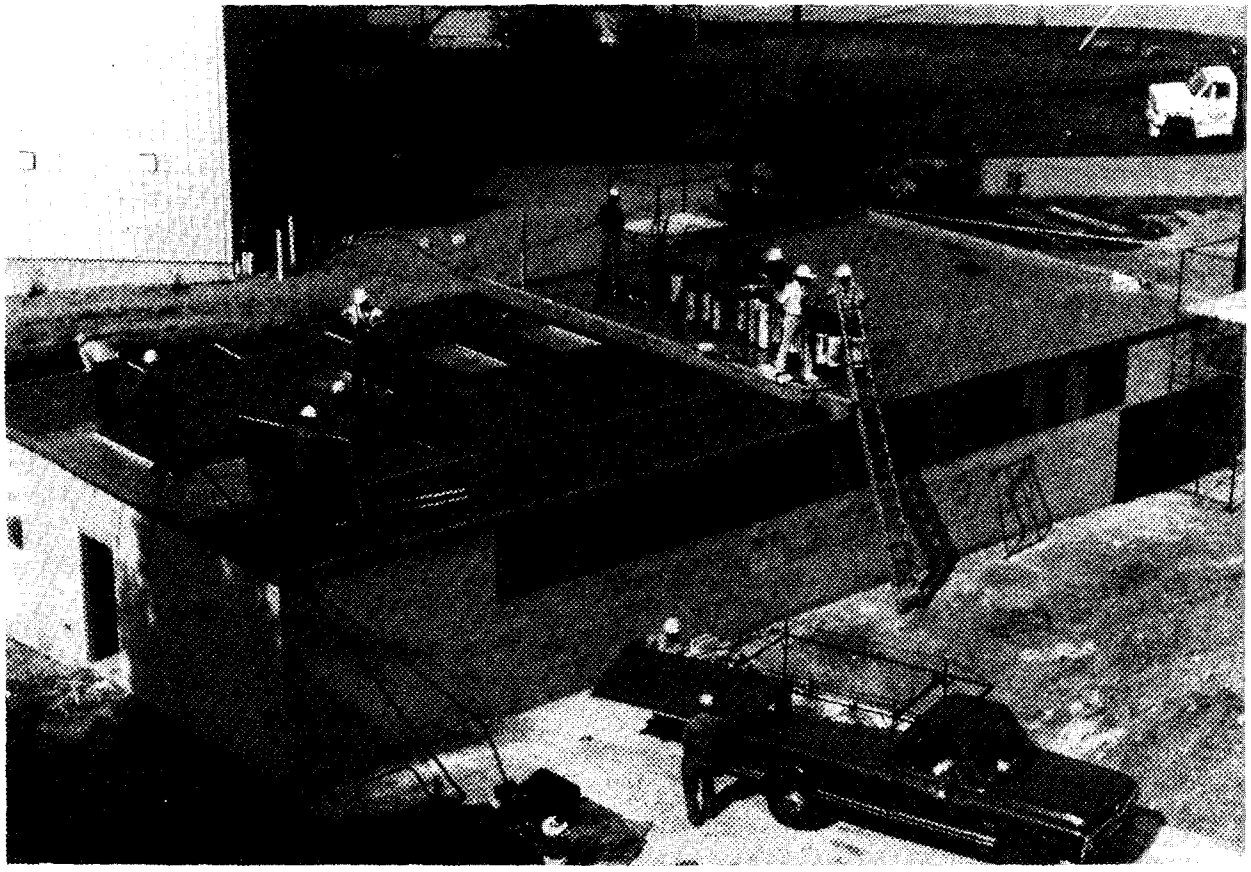


Fig. 38. ORNL and DOE are participating in joint government-industry efforts to reduce the use of chlorofluorocarbon (CFC) compounds in the buildings industry. The objective is to compare the field performance of polyisocyanurate foam roofing insulation produced with greatly reduced ozone-depletion-potential HCFC gases to the performance of conventional insulations produced with CFC-II. The activity required new test facilities at ORNL cofunded by DOE and industry groups.

worldwide use of CFCs has increased the urgency of this task. During the past year, ORNL generated the first known experimental data on system performance of seven potential CFC substitutes. ORNL worked with Du Pont to develop the mixture of refrigerants that is now the leading candidate as a near-term replacement for R12. Three types of heat-actuated heat pumps are under development by industrial subcontractors: absorption cycle, Stirling cycle, and internal combustion. ORNL has identified a new absorption cycle (the triple-effect cycle) with up to twice the cooling performance potential of the best current cycles, and patent rights have been waived to Martin Marietta Energy Systems, Inc. This technology could give the United States a multibillion-dollar worldwide market in cooling systems for commercial buildings (Fig. 39).

The Buildings Technology Transfer project provides resources for strategy development and evaluation of technology transfer. This activity also conducts outreach efforts that go beyond the scope of R&D projects for building components. Specific current tasks include working with universities on education and training; providing support to the Office of Buildings and Community Systems in producing publications; and coordinating with other outreach organizations such as the Conservation and Renewable Energy Inquiry and Referral Service, the Office of Scientific and Technical Information, the National Appropriate Technology Assistance Service, the Center for Analysis and Dissemination of Demonstrated Energy Technologies, and the DOE Office of State and Local Programs.

During the past several years, ORNL has taken a lead role in exploring the potential of

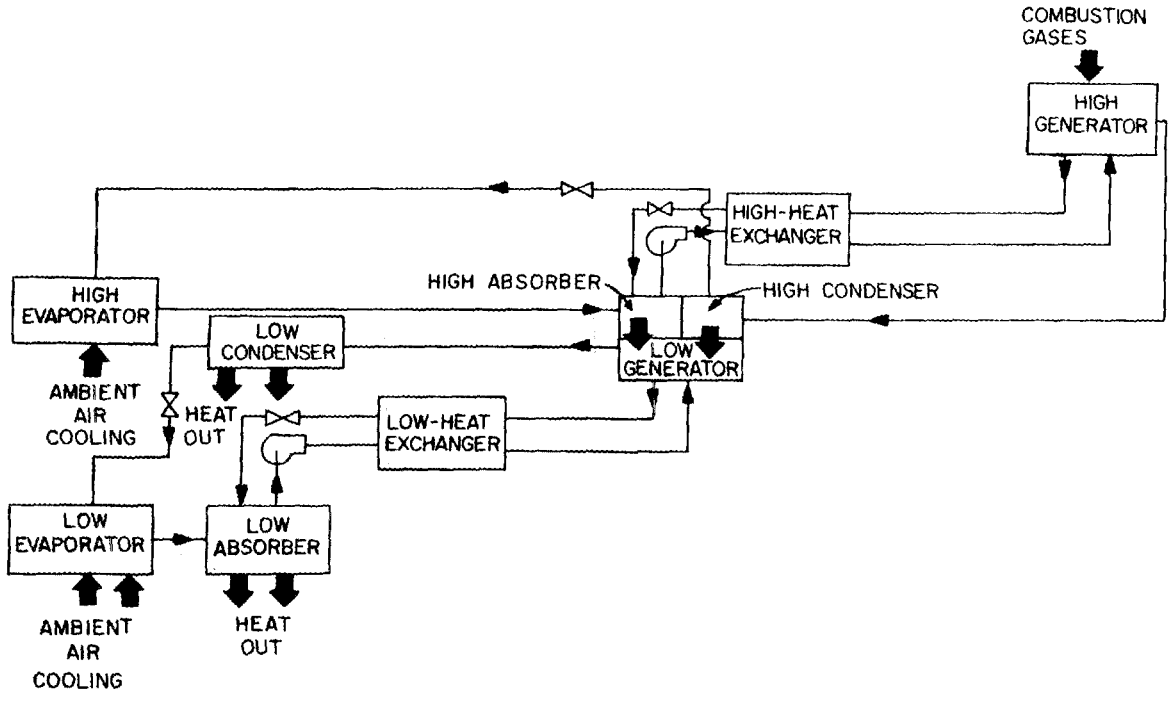


Fig. 39. ORNL is developing gas-fired heating and cooling equipment. This equipment avoids the inefficiences of electric power generation. A triple-effect gas-fired absorption air chiller recovers waste heat from a high-temperature cycle to operate a low-temperature cycle. The resultant system is 50% more efficient than today's best gas-absorption equipment. A device for commercial systems is expected to be available in 4 years.

Integrated Resource Planning (also called Least Cost Planning). In this concept, utility planning includes end-use energy conservation options in addition to energy supply options (Fig. 40). During FY 1990, DOE has selected Integrated Resource Planning as an initiative area, and it is expected that ORNL funding for this project will increase in FY 1991 and subsequent years.

provide data in support of two industrial subcontractors.

A study in FY 1989 has provided DOE with updated data on prospects for increased recycling of plastic scrap. A major assessment was completed in FY 1990 to determine the extent of industrial needs for new technologies in continuous fiber ceramic matrix composites. This task produced a

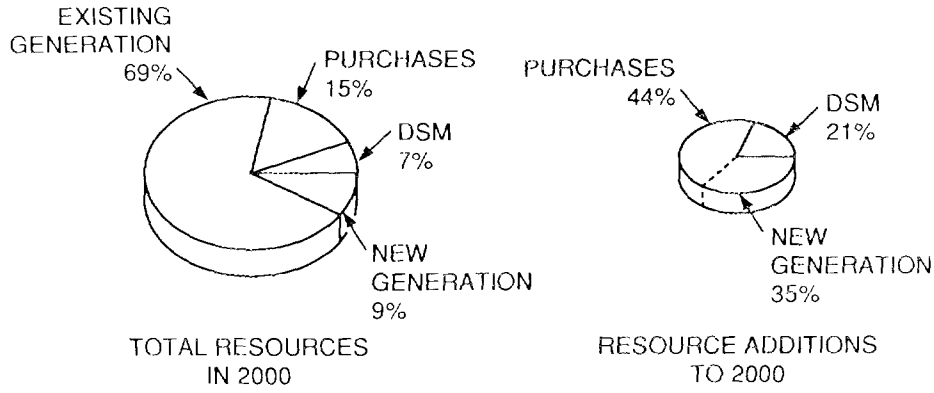


Fig. 40. Demand-side management (DSM) practices are playing an increasing role in utility planning. A recent review of long-term resource plans for 15 major U.S. utilities suggests that about 20% of new capacity growth will be met by demand-site management.

ED—Industrial

ORNL is responsible for two continuing projects in Waste Energy Reduction. The first of these, Materials for Waste Heat Utilization, provides materials technology support to DOE and its contractors in support of advanced heat-exchanger development. Recent work has included evaluating the corrosion of several candidate ceramics for industrial projects and evaluating coatings to reduce corrosion. ORNL has also completed the design and construction of a controlled temperature corrosion probe. This unit has been tested in the ORNL steam plant and has been modified for use in an industrial furnace.

In the second project, Chemical Heat Pumps, the objective is to develop heat-pump technology for recovering industrial and process waste heat. A heat- and mass-transfer apparatus is being used to

detailed R&D plan for a possible new initiative by the Office of Industrial Programs and may be followed in future years by significant research activities.

Under Industrial Process Efficiency, ORNL is working to develop materials for use in a process which separates oxygen from air in a corrosive nitrite-nitrate medium. Thus far, iron aluminide has been identified as the most promising candidate. Development of iron aluminide is proceeding under joint support by the ED and EG programs. A new project, development of a magnetohydrodynamic atomization nozzle for spray casting steel, was initiated in FY 1989 in coordination with EG&G Idaho and the Massachusetts Institute of Technology. This project is part of the program known as the Metals Initiative. Technical feasibility of the ORNL process has been demonstrated with low-melting alloys at laboratory scale. The next step, now

under way, will be to build and operate equipment which will demonstrate the process with steel and with greater throughput.

The level of activity by ORNL on Industrial Programs is expected to increase substantially during the planning period, in response to growing recognition of the central role of materials technology in industrial energy efficiency.

EE—Transportation

ORNL is responsible for two projects in transportation: Ceramic Technology for Advanced Heat Engines and HTML user centers; ORNL also participates in the Alternative Fuels Utilization Program.

The Ceramic Technology for Advanced Heat Engines project is developing the industrial technology base needed for the use of structural ceramic components in advanced automobile and truck (diesel and gas turbine) engines (Fig. 41). The energy-savings potential of ceramics in transportation is based primarily on higher operating temperatures and secondarily on reduced friction, weight, and inertia. The major part of the work is done through cost-shared subcontracts to the ceramics industry. The project is proceeding toward a set of performance and reliability goals defined by a multiyear plan. Among many achievements during the past year was the publication of Volume I of the International Energy Agency (IEA) powder characterization report. This 2-year R&D effort was part of an international cooperative program between the United States, West Germany, and Sweden. In addition, an update report for the Ceramic Technology Project Database was issued. Unlike previous reports, which concentrated on one class of ceramics per report, this report contained new test results on several classes of ceramic materials including zirconias, silicon carbides, and silicon nitrides.

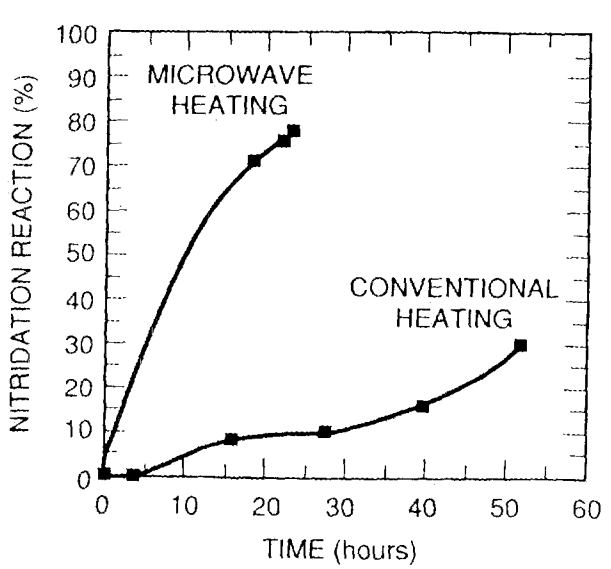


Fig. 41. The Ceramic Technology for Advanced Heat Engines project conducts research on microwave processing of silicon nitride. The objective of the research is to accelerate nitridation, permit sintering to high density, and lower sintering temperature.

The HTML, which was completed in FY1987, houses laboratories and special equipment to support the Office of Transportation Systems, other DOE offices, universities, and industry in advanced materials research. Four user centers are operated within the HTML, with funding designated for this purpose. Through June 1990, user agreements had been established with 37 universities, 55 industrial firms, and 4 government laboratories. More than 100 separate research projects had been completed or were under way. A new initiative to expand the usefulness of the HTML through a fellowship program has been proposed. The initiative would provide postdoctoral, faculty, and industrial fellowships, each for a limited period of research, in one of the four HTML user centers.

The rapid increase in applications for use of the HTML is expected to require increased funding in future years.

The objective of the Alternative Fuels Utilization Project is to establish a technical data base on the utilization of nonpetroleum fuels, including gaseous fuels, alcohols, and fuels derived from shale or tar sands. Analysis of recently compiled data from Federal Methanol Fleet vehicles has revealed greatly different wear rates depending on the season of the year. While this

phenomenon is known to happen with gasoline vehicles, the magnitude of the differences for methanol vehicles was unexpected. In other work, a data base for alternative fuels was completed under subcontract with Caterpiller. This project gives some of the most up-to-date comparisons of methanol, natural gas, and dual fuels in truck engines and shows unexpectedly high concentrations of unburned fuel and formaldehyde from both methanol and natural gas. Increased funding on alternative-fuels research may be forthcoming in the next few years as a result of intensified emphasis on regional air quality problems. However, the extent of ORNL funding is uncertain because of a recent DOE decision to transfer field management responsibility to the Solar Energy Research Institute.

An additional project, Transportation Systems Research, provides analysis of transportation data, such as vehicle fuel economy, sales, and technology trends.

EF—State and Local Programs

During FY 1990, ORNL assisted DOE in developing a plan for evaluating the impact and potential of its Weatherization Assistance Program. It is anticipated that ORNL will implement the plan over the next 3 to 4 years, using a nationally representative sample of program participants, a sample of fuel oil participants from nine northeastern states, and matched control groups. Data on numerous aspects of the program, its participants, and its unserved eligible clients will be gathered from a variety of sources, including local and state agencies, household surveys, on-site building inspections, fuel and indoor-temperature monitoring, electric and gas utilities, and the 1990 Census of Population.

An ORNL initiative is Energy Technologies for Developing (and Eastern European) Countries. Under this initiative, ORNL is proposing to set up a Center for Global Energy Efficiency. The purpose of the center is to assist developing and Eastern European countries to identify and evaluate efficiency-improving technologies and to encourage linkages with U.S. equipment manufacturers and vendors as a "one-stop shopping" center. It will also assist in developing energy-efficiency programs and projects, R&D agendas, and data bases related to efficiency improvement in these countries.

EG—Multisector

ORNL has a continuing role in several parts of the DOE program entitled Energy Conversion and Utilization Technologies (ECUT). The role of ECUT is to span the gap between basic science and engineering development of conservation technologies. Thus ECUT provides the technology base for efficiency improvements in all end-use sectors. ORNL participates in the Materials, Tribology, Biocatalysis, and Combustion projects in ECUT.

The ORNL research in ECUT Materials currently covers seven areas: superconducting materials, high-temperature materials, materials by design, lightweight materials, corrosion-resistant materials, thermally insulating materials, and materials-processing technology. In Tribology the ORNL research is in the area of ceramic friction and wear. Our research in Biocatalysis seeks to develop continuous bioreactor technologies for production of chemicals such as ethanol. The ORNL effort in the Combustion project consists of the development of microemulsions for transportation fuels.

During FY 1990, numerous milestones were reached in ECUT Materials. Prototype turbochargers, made of the Ni_3Al alloys developed at ORNL in the ECUT Materials program, are being fabricated and evaluated by the Cummins Engine Company. Numerous tests are and will be performed to evaluate their acceptability for use in large diesel engines (Fig. 42). In another ECUT Materials task, significant progress was made in the development of high-temperature superconducting magnets for a high-efficiency motor. Y-123 films grown on single-crystal yttria-stabilized ZrO_2 substrates were found to have a critical temperature of 85 K. In ECUT Tribology,

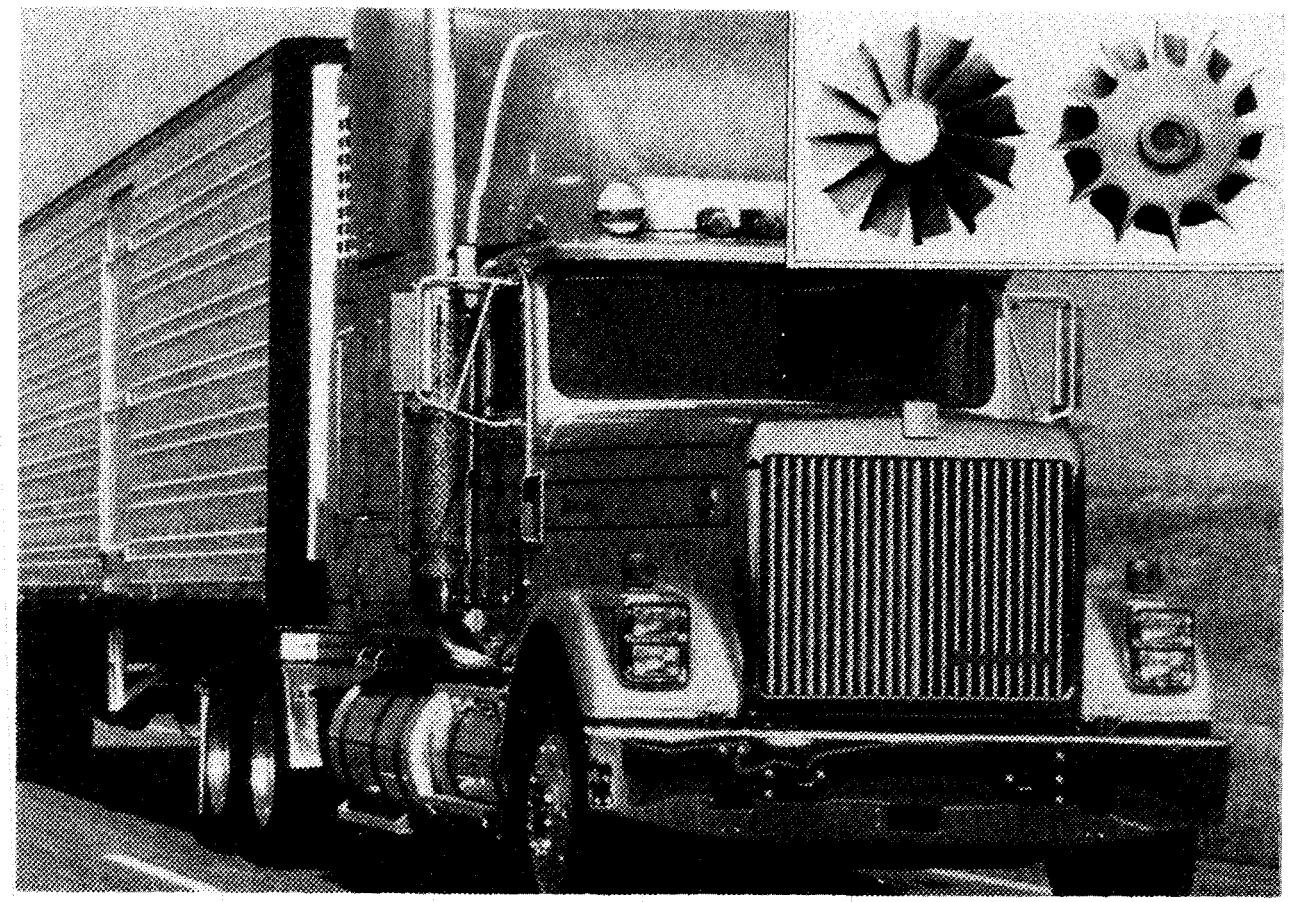


Fig. 42. The development of Ni_3Al alloys may permit more energy-efficient engines to be built. Currently, alloy composition and casting conditions are being optimized to improve properties to prototype turbochargers being tested for use in large diesel engines.

a definitive study of the friction and wear behavior of nickel aluminides has been published. ORNL's expectation is that funding for ECUT will remain at the current level or increase in future years.

An additional project within the EG program is the evaluation of the Energy-Related Inventions Program (ERIP). The evaluations consider both the effectiveness of the project in helping inventors to commercialize their ideas and the extent of resulting energy savings. ORNL analysis of the cost of commercialization found that for $1 spent in the initial year of research, $37 more were needed to reach limited production. Technologies supported by the program have achieved $400 million in sales through 1988. Estimated tax returns generated by these technologies suggest a significant return on the public investment in ERIP.

Assistant Secretary for Fossil Energy

ORNL programs for the Assistant Secretary for Fossil Energy cover the following areas: coal, clean coal technology, support to the Strategic Petroleum Reserve, and support to the Naval Petroleum and Oil Shale reserves. The principal

focus of ORNL's fossil-energy activities, however, is coal. The coal budget is anticipated to remain fairly level in FY 1991 and to increase in FY 1992, with the increase due primarily to additional efforts in materials; chemical processing and bioprocessing of coal; and environmental, safety, and health areas (Table 38).

deposition process developed at ORNL. Ceramic composites have a variety of applications in fossil-energy systems such as high-temperature heat exchangers and hot-gas cleanup filters. Current work also emphasizes understanding the nature of the fiber/matrix interface with the aim of improving the mechanical properties of composites.

Table 38. Assistant Secretary for Fossil Energy major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1989	1990	1991	1992
AA	Coal	5.8	5.6	5.6	9.8
AZ	Innovative Clean Coal Technology	1.1	0.5	0.8	1.0
CB	Naval Petroleum and Oil Shale Reserves	0	*b*	0	0
SA	Strategic Petroleum Reserve	0.7	0.2	0.4	0.4
Total		7.6	6.3	6.8	11.2
Percentage of total Laboratory funding—BA		1.6	1.3	1.0	1.5

[a]Figures include operating BA, capital equipment, and construction, if any.
[b]Less than $0.1 million.

AA—Coal

Materials research activities, including management (with the DOE Oak Ridge Office) of the Fossil Energy Advanced Research and Technology Development Materials Program, comprise the major portion of the coal budget. It is expected that the materials area will proceed at approximately the same level and emphasize the same research areas through FY 1991; we have proposed a significant increase in FY 1992. From FY 1992 through FY 1996, additional efforts will focus on solid-state electrolyte systems, development of advanced coatings and claddings, inorganic membranes, and technology transfer.

Fiber-reinforced ceramic composites with improved strength and toughness are being produced by the chemical vapor infiltration and

Ceramic membranes for the separation of gases in high-temperature and hostile environments are being developed and tested. Other work is devoted to the microwave sintering of ceramics. This technology will be important in the fabrication of electrode and electrolyte materials with improved electrical properties for solid oxide fuel cells.

ORNL is developing advanced austenitic alloys for use in fluidized-bed and pulverized-coal combustion power plants. The objective of this work is to modify existing alloys that will satisfy the strength and corrosion-resistance requirements of high-temperature and high-pressure, second-generation power plants. Intermetallic alloys based on Fe_3Al are being developed for applications in which superior corrosion resistance and strength are required. Improved room-temperature ductility and resistance to hydrogen embrittlement will

continue to be emphasized in the next several years. Current materials and designs for tubesheets and manifolds for hot-gas filter systems are being examined, with the aim to recommend a tubesheet material suitable for long-term operation of these systems.

With a specially modified scanning electron microscope, erosion processes can be observed in situ, leading to valuable data on the mechanisms of the erosion process and an understanding of the formation and adherence of protective oxide scales. Corrosion research at ORNL centers on studies of the formation and breakdown of protective oxide scales, particularly in sulfur-containing atmospheres and on the effect of environment on corrosion of iron aluminides.

ORNL has a commitment to transfer the technology developed in the Fossil Energy Materials Program to others in the fossil energy community. ORNL is working with two industrial firms and the Morgantown Energy Technology Center to produce and test sintered porous metal filters made from iron aluminides. Another significant technology transfer effort was accomplished through the establishment of a subcontract with 3M Company for the development and transfer to industry of a process for fabricating full-size ceramic fiber-ceramic matrix composite filters, utilizing technology developed at ORNL.

Research is also being conducted on the structure and chemistry of coal surfaces and interfaces to understand the complex processes and reactions occurring during the combustion of coal. Recent results have revealed that the hydrogen bonding structures of coal and the surface area of finely divided coal are expected to have a significant impact in the understanding of the properties of coal.

Coal conversion work at ORNL involves bioprocessing of coal and the evaluation of coal-derived liquids produced from mild gasification processes. Bioreactor concepts that maximize coal solubilization and product yields are being examined. For the first time, bacteria have been shown to interact with a bituminous coal in a hydrogen environment for the biological solubilization of coal.

AZ—Innovative Clean Coal Technology

Work on the Clean Coal Program (CCP) includes support in the areas of environment and materials. CCP is an important activity which is jointly funded by DOE and industrial organizations. Three solicitations have been completed by DOE, and fourth and fifth solicitations for CPP are planned for future years.

An important part of ORNL's involvement in the CCP is environmental technical support to DOE in the preparation of NEPA reviews of site-specific projects. Materials failure analyses, critical to the success of advanced clean coal technologies, continue to be conducted for the Pittsburgh Energy Technology Center. Work related to CPP is expected to increase in the next 5 years.

CB—Naval Petroleum and Oil Shale Reserves

ORNL staff members are performing assessments of a naval petroleum reserve in Wyoming and a naval oil shale reserve in Colorado. The objective of this work is to conduct an Environmental Compliance Assessment covering all environmental regulations to strengthen the environmental programs at these sites and to ensure full environmental compliance.

SA—Strategic Petroleum Reserve

ORNL is performing work for the Strategic Petroleum Reserve (SPR) Program in two areas. One area is concerned with the development of a baseline data set for specific metals and organic chlorine in crude oils. The second area involves assistance to the SPR in the assessment of alternative methods of financing oil acquisition and in the development of models for planning the capacity and management of SPR. It is expected that SPR support activities will increase moderately in the next 5 years.

Assistant Secretary for Environment, Safety, and Health

ORNL work for the assistant secretary for environment, safety, and health includes development of environmental policy assessment methodologies and models; application of these to analyze proposed and existing environmental legislation and regulation; planning and assessment of technologies for dealing with radiological emergencies; participation on DOE Tiger Teams; and training of DOE and contractor staff in compliance with environmental laws and regulations (Table 39).

activities, including the tracking and analysis of regulations and the development and dissemination of regulatory information and guidance. In FY 1990, in response to Secretary Watkins' ten-point initiative for improving DOE's environmental performance record, ORNL provided substantial new support for training in environmental laws and regulations. The development and implementation of training courses in environmental regulation for both senior and mid-level DOE managers will continue. We anticipate a new technical support role with the Environmental Compliance Division in FY 1991. We can assist them in evaluating the compliance status of DOE facilities nationwide and in developing data bases to track compliance status.

Table 39. Assistant Secretary for Environment, Safety, and Health major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1989	1990	1991	1992
HA	Overview and Assessment	7.9	4.6	4.2	4.4
Percentage of total Laboratory funding—BA		1.7	0.9	0.6	0.6

[a]Figures include operating BA and capital equipment, if any.

HA01—Environment, Safety, and Health

The Laboratory continues to provide technical support to all offices under the Deputy Assistant Secretary for the Environment. Activities include regulatory analysis, analysis of environmental impacts of energy development, technical input to policy analysis, technical guidance on compliance with environmental regulations, and training.

Environmental Guidance and Compliance ORNL will continue to provide extensive technical support to the Office of Environmental Guidance and the Office of Environmental Compliance. Long-standing work for this office encompasses a variety of regulatory

NEPA Project Oversight ORNL technical support to the Office of NEPA Project Oversight will expand because of the secretary of energy's goal to ensure agency compliance with NEPA. Technical support includes development of guidance for compliance with NEPA, preparation of related background information, review of NEPA documents, NEPA training, and assistance at DOE Headquarters. Major initiatives that relate to the secretary's ten-point plan and Secretary of Energy Notice SEN-15-90, "Revisions to DOE Order 5440.1C and to DOE Guidelines" (February 5, 1990) will include (1) providing technical support for evaluating compliance with NEPA at all DOE facilities (e.g., Tiger Teams) and (2) training mid-level DOE management staff and operating contractors to ensure that personnel responsible for NEPA compliance

understand the statute, the Council for Environmental Quality regulations, the DOE NEPA guidelines, and their responsibilities in the preparation of the various levels of NEPA documentation.

Environmental Audit ORNL support to the Office of Environmental Audit in completion of their Environmental Survey was completed in FY 1990. We will initiate a new technical support role for this office which will include updating audit protocols and checklists, participation on audit teams, and data base development tasks to track audit results and changing regulations. ORNL expertise in environmental and health risk analysis is available to help prioritize actions required to comply with environmental regulations, federal facilities agreements, and consent orders.

Safety Policy and Standards Sponsors of the Emergency Technology Program (ETP) are reorganizing and will modify the mission of the program. Under the ETP, ORNL personnel review and assist in emergency planning and preparedness for environmental protection and public safety.

ORNL has developed the capability for conducting large-scale hydrogeological and environmental characterization activities that are essential to addressing the contamination problems that occur on many of the DOE sites. An increasing interaction with regulatory agencies is creating the need for a uniform, efficient, and well-organized approach to development and initiation of site-wide characterization studies. ORNL will plan to serve as the coordinating center for characterization of selected DOE sites throughout the country, drawing heavily on the experience developed in work done on the Oak Ridge Reservation, which is hydrogeologically the most complex of any of the sites.

ORNL support to the Office of Environmental Audit in completion of their environmental survey terminated in FY 1990. ORNL technical support in site-prioritization efforts, environmental audits, and emergency-response R&D is available.

Energy Information Administration

The purpose of this program work is to provide the Energy Information Administration (EIA) a coordinated approach and a center of responsibility at ORNL by which EIA's objectives and technical needs may be met (Table 40).

ORNL proposes to continue supporting EIA through (1) economic analysis in support of issue analysis and in support of EIA's ongoing energy-modeling activity; (2) analysis and evaluation of EIA's quality assurance activities, particularly through expert reviews; and (3) technical analyses, including engineering studies. In addition, ORNL

Table 40. Energy Information Administration major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1989	1990	1991	1992
TA	Collection, Production, and Analysis	1.6	1.0	1.3	1.6
Percentage of total Laboratory funding—BA		0.3	0.2	0.2	0.2

[a]Figures include operating BA and capital equipment, if any.

will apprise EIA of newly developing areas of expertise:

- information systems development,
- creative file structures and maintenance,
- artificial intelligence (AI) and expert systems,
- the development of an international energy data base through the ORNL/Agency for International Development (AID) program, and
- a growing number of analyses of technological change.

Funding for future years is expected to be stable in real dollars.

Other DOE Programs and Installations

ORNL continues to provide support to other DOE offices and installations including the Assistant Secretary for Management and Administration; the Office of Policy, Planning, and Analysis; and other DOE contractors and operational offices (Table 41).

Table 41. Other DOE programs and installations[a]
[$ in millions—budget authorization (BA)]

	Fiscal year			
	1989	1990	1991	1992
Assistant Secretary for Management and Administration	0.3	0.9	0.1	0.2
Office of Policy, Planning, and Analysis	0.4	1.2	1.6	1.6
Assistant Secretary for International Affairs and Energy Emergencies	0.2	0.1	0.2	0.3
DOE contractors and operations offices	31.7	32.9	25.5	26.6

[a]Figures include operating BA, capital equipment, and construction, if any.

Assistant Secretary for Management and Administration

ORNL is conducting energy management studies in Laboratory facilities to identify retrofit projects to achieve the energy-consumption and efficiency goals established by DOE and reflected in ORNL's 10-year energy management plan. The following tasks are included: chilled-water free cooling project; HVAC control system; Building 4500-S project; proposed HVAC control projects for Buildings 4500-N, 4501/4505, 4508, 5500, and 3500; and studies to improve lighting efficiency and HVAC controls in ORNL facilities.

Office of Policy, Planning, and Analysis

Work for the Office of Policy, Planning, and Analysis (PE) will include research on transportation, energy efficiency, infrastructure costs associated with alternative fuels, alternative fuels supply issues and effects on energy security, consumer choice and demand issues for alternative fuels, and automobile and light-truck fuel-economy standards and analyses in support of the Interagency Task Force on Alternative Fuels. ORNL will also perform research and analyses in support of PE's role in developing the National Energy Strategy.

For 16 years, ORNL has supported the DOE Office of Environmental Analysis (OEA) in the development of energy resource assessment models and in the provision of background research for

various energy and environmental policy issues. This support will continue with increased attention to environmental analyses in support of the National Energy Strategy process. The OEA is funding a variety of projects including a flue-gas desulfurization information system, development of residuals generating model for the National Energy Modeling System, analysis papers to support OEA's role in the National Energy Strategy process, studies of international developments in global climate change, a study of the relationships between automotive fuel economy and hydrocarbon emissions, a study characterizing critical loads of sulfur deposition acceptable for maintaining aquatic and terrestrial ecosystem structure and function, and a study projecting future pollution resulting from power plant life extension.

Other DOE Organizations

ORNL performs numerous small tasks, frequently on an ad hoc basis, for a number of other organizations within DOE, including the Assistant Secretary for International Affairs and Energy Emergencies, the Economic Regulatory Administration, the Federal Energy Regulatory Commission, the Oak Ridge Operations Office, and others. These activities are distributed among the various Laboratory programs and together make up about 5% of the total Laboratory funding.

A program began in FY 1989 for the Office of Operational Safety, Transportation, and Facility Safety Division. This task provides evaluations, reviews, technical analyses, and development support in transportation areas related to hazardous materials, including regulatory compliance evaluations and appraisals; evaluation of exemption applications; safety analysis reports; proposed regulations, standards, and orders; formulation of safety-related requirements; and preparation of supporting documentation. The program includes support for the actual performance of compliance appraisals, safety-related program evaluations, and evaluation of regulatory-related activities. This program is expected to experience moderate growth through FY 1991 and then remain stable.

For the past several years, ORNL's Energy Division has conducted state-of-the-art program evaluation research for Bonneville Power Administration's Office of Energy Resources. This research has focused primarily on the performance of residential energy retrofit programs. Bonneville has operated a Residential Weatherization Program since 1981. ORNL's evaluation research has centered on the energy saved by this program, over time. Recent research has expanded into issues concerning the energy efficiency of new residential buildings, compliance with Bonneville's Model Conservation Standards, the fuel choices of customers, and integrated resource planning. The Energy Division will also extend its leadership in the fields of AI and power systems by developing an expert-system prototype to process Bonneville's microwave communication system alarms.

Other ORNL Programs

Reactor Operations

This ORNL organization is responsible for the operation, maintenance, and support of ORNL's research reactors so that they safely, reliably, and efficiently fulfill their intended research, isotope-production, and training functions. The Research Reactors Division carries out this work, interacting with 11 other ORNL divisions and organizations that either conduct reactor-based research or support reactor operations.

Laboratory and division management are committed to maintaining a proactive approach in operating the research reactors. This approach will include securing all resources necessary to ensure safe, efficient, reliable operation; top-management support; and a continued pursuit of excellence. The philosophy of total-quality management, as well as the requirements of Environmental Safety

and Health (ES&H); Institute of Nuclear Power Operations (INPO) guidance; and compliance with DOE, OSHA, EPA, and DOT regulations will continue to be emphasized.

ORNL's research reactors include one "Class A" reactor (HFIR), and three "Class B" reactors [Tower Shielding Reactor II (TSR-II), the Health Physics Research Reactor (HPRR), and BSR]. In addition, two reactor facilities [the Critical Experiments Facility (CEF) and PCF] are in standby status and one reactor [the Oak Ridge Research Reactor (ORR)] has been shut down and defueled.

The HFIR was restarted in January 1990 and resumed full-power operation in May 1990. Operating at a maximum level of 85 MW, the HFIR is the world's most powerful research reactor and home of the Neutron Scattering Facility. Other uses of HFIR include vital materials research and production of radioisotopes to fill important medical and research needs.

A significant redirection of resources occurred with the discovery of some small particles of radiation outside of radiation areas at the HFIR. This necessitated a large reallocation of finances and personnel to assess and ensure contamination-control regulatory compliance.

Maximizing the reactor's availability for research, material studies, and isotope production is a priority in HFIR planning. Reestablishing a reliable schedule for operation will enable ORNL users to (1) plan their own schedules, (2) respond to the needs of researchers outside of ORNL who have requested reactor time, and (3) market the reactors to others whose research needs can best be served here.

TSR-II, a Class B reactor, was restarted in December 1989 and resumed its primary research program, the Japanese/American Shielding Program of Experimental Research (JASPER), in January 1990. TSR-II plans were modified significantly when the decision was made to replace the reactor's control sphere. This change-out was successfully completed during a 6-month outage for that purpose in the summer of 1990. Future plans include additional shielding experiments (following completion of JASPER) and consideration of the feasibility of resuming cask-drop tests from the towers at the facility to determine the reliability of casks under simulated accident conditions. As with the HFIR, one of the key missions of the TSR-II is to work toward increasing its availability as a research tool to better serve the current users and to enhance future-use planning.

A decision was made recently by the DOE Office of Energy Research to shut down the HPRR, which is currently on standby. Although users with pressing needs for the reactor were identified, approximately one-half of the financial support needed for restart was located, and a business plan was developed based on cost-recovery operation after restart, sufficient programmatic resources to support all restart costs were not evident, and a safeguards and security initiative necessitated movement of fuel-bearing components to storage where standby costs could be reduced.

The BSR has been on standby for over 3½ years. If state-of-the-art equipment could be installed, the reactor would be an excellent training facility. A decision regarding restarting the BSR will be made in the near future.

At CEF (also on standby), extensive cleanup and refurbishment have been completed. A technical decision will be made as to whether the facility will be required in support of HFIR operations.

A decontamination and decommissioning plan has been submitted to DOE for the ORR, which is already shut down and defueled.

Continuation of active support for the development and construction of the ANS, which will ultimately replace HFIR, is an additional and significant mission for Reactor Operations.

A new Laboratory initiative has been proposed to DOE for establishment of a Center for Excellence in Research Reactors (CERR) (see Initiatives section), which would help to alleviate a serious national dilemma caused by the decline in the number of research reactors in the country and by an increasing need for such facilities. CERR would match users with available research reactors.

Plans call for a continuation of an active leadership role in the Association for Excellence in

Reactor Operations, formed by operators of DOE Class A reactors for the purpose of enhancing safe, secure, and environmentally sound operations and total quality performance by promoting excellence in all phases of operations.

Changes in the nature and level of work involved in Reactor Operations have been dramatic as the transition has been made from all ORNL research reactors being shut down to operating two reactors and determining the feasibility of restarting others as well as bringing additional reactor facilities back into use. Basically, the effort applied to restart activities has been redirected to achieving excellence in operating the restarted reactors.

Perhaps the most dramatic change that has occurred has been in the "culture" or attitude and work environment created by people at all working levels. A major commitment has been made to continuing to upgrade this culture. Another significant change has been in the evolution of additional requirements for more prompt, more thorough, and more detailed reporting of events to DOE. Resources dedicated to fulfilling these requirements have increased, and efforts have been intensified to provide prompt, factual reports that are in compliance with DOE regulations and to assist DOE in interpreting reactor events.

In accomplishing the restart of HFIR and TSR-II, some important lessons were learned and some notable achievements took place. Sharing the knowledge gained has become a part of the Reactor Operations role.

"Lessons Learned" briefings have been given to many organizations both within and outside of Energy Systems. The Research Reactors Division (RRD) Quality Assurance Program has been cited on more than one occasion as one that could be drawn upon in planning thorough commitments to QA, and the HFIR itself has been designated as a "model facility" for Energy Systems. Additionally, RRD's training and accreditation programs have helped to provide a road map for other ORNL divisions and programs and other DOE contractors; the system for tracking reactor operations commitments has been tailored to fit the needs of many other organizations and has been used in planning a central Energy Systems commitment-tracking program; the measures taken to control radioactive contamination at ORNL have been modeled on those in use for HFIR; and the system used in the document-control center has likewise been applied to fit the needs of many other DOE programs carried out by Energy Systems.

The current mission of Reactor Operations is to ensure, through management leadership and controls, that the lessons of the past are not repeated and to strive to be the best of DOE's reactor operating contractors. One of the many management tools used to measure progress is a system of performance indicators, which is carefully monitored on a monthly basis. Utilization of applicable nuclear industry standards will also continue.

Planning exercises have identified 22 strategic issues and action items, each of which is detailed in the RRD strategic plan. Included are a marketing plan for promotion of reactor capabilities, a funding plan for anticipated capital improvements, and a long-term plan for fuel-shipping casks.

Robotics and Intelligent Systems Program

The Robotics and Intelligent Systems Program (RISP) serves as the focal point at ORNL for R&D in remote systems, robotics, teleoperation, and related aspects of intelligent machines. The program is interdisciplinary in nature and uses the expertise of scientists and engineers from several research and support divisions of ORNL. RISP conducts research for the DOE, DOD, the National Aeronautics and Space Administration (NASA), and other sponsors.

RISP addresses R&D goals for extending human senses and dexterity into unstructured and/or semistructured hostile environments. The goals are to develop systems that minimize human risk by allowing effective remote operations in hazardous environments while minimizing human errors and enhancing overall system efficiency

through automation of routine or repetitive tasks. The research includes developing an appropriate combination of teleoperation and autonomous operation to achieve the necessary level of task performance while maintaining robust human-machine interaction. The programs cover activities in basic R&D as well as development and full-scale demonstrations of prototype systems, including remote operations and maintenance.

RISP performs R&D for four major DOE programs. Research into intelligent machines is performed for DOE's Office of Basic Energy Sciences Engineering Research Program. Development of robotic systems and techniques to perform surveillance and manipulation functions within a nuclear power plant is pursued for DOE's Office of Nuclear Energy. Figure 43 illustrates the HERMIES-III robot performing a simulated chemical spill clean-up. RISP performs remote equipment design and remote mockup demonstrations for the CIT and for the ITER, a planned cooperative effort among the United States, the European Community, and Japan. In addition, a major new program for the DOE Office of Environmental Restoration and Waste Management involves national planning and initial technology demonstration of robotics technology for support of the national restoration efforts. Key areas of focus for ORNL include underground storage tanks and buried-waste retrieval.

In research programs sponsored by NASA, RISP has designed, developed, and delivered to Langley Research Center the Laboratory Telerobotic Manipulator system, a reconfigurable, modularized, telerobotic manipulator optimized for microgravity operation research. In addition, a Microgravity Manipulator Prototype was developed for Lewis Research Center to provide a test bed for research into space experiment automation issues. A feasibility study for the Strategic Defense Initiative Organization (SDIO) addressed the feasibility of space-based reactor remote retrieval.

Under the auspices of the U.S. Army Human Engineering Laboratory, RISP personnel are contributing to the Robotics Test Bed Program, an element of the Office of the Secretary of Defense

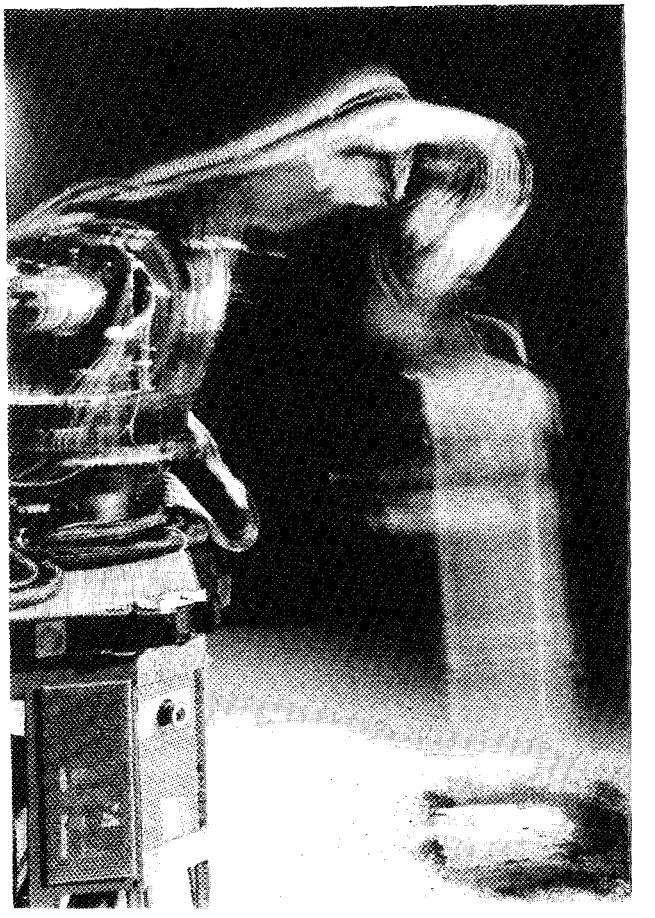


Fig. 43. ORNL researchers achieved a significant milestone by demonstrating the autonomous (without human intervention) cleanup of a simulated spill in the Center for Engineering Systems Advanced Research, using the HERMIES-III robot.

Unmanned Ground Vehicles Master Plan program, which is assessing opportunities for new robotic combat functions. For the U.S. Army Harry Diamond Laboratory, the operational benefits of near real-time combat information management to the tactical commander have been investigated on the Combat Information Processor program. Development of advanced material-handling vehicles with increased soldier efficiency through man/machine synergy is being investigated in the All-Terrain Lifter, Articulated System (ATLAS) program for the U.S. Army Belvoir Research Center. A U.S. Army Laboratory

Command sponsored Advanced Concepts Technology program is examining efficient use of combined mobility and manipulation systems. Finally, the Future Armor Rearm System (FARS) program is examining automatic ammunition resupply systems for the next generation of the M1 tank. The loading system will provide full nuclear, chemical, and biological contamination protection for soldiers. Figure 44 illustrates the FARS concept with models. This project is sponsored by the U.S. Army Program Manager Office for Ammunition Logistics.

RISP builds upon ORNL's strengths in remote technology, teleoperations, robotics, and autonomous machine research. Program activities that cut across the entire spectrum of related technologies are under way for DOE, DOD, and NASA sponsors. Because research for these agencies often employs similar technologies, significant cost savings can be realized through integration of resources at the working level. The integration of teleoperations and autonomous machines will continue to evolve, and RISP should be a major contributor to that process.

Office of Risk Analysis

The Office of Risk Analysis (ORA) within Health and Safety Research Division is a center of focus for risk-analysis research and applications. Assistance is provided to most Energy Systems facilities through the Environmental Restoration Program and in response to special needs, as well as to other DOE and WFO programs. The ORA is also involved in conducting local, national, and international workshops and symposia on various aspects of risk analysis. Considerable outreach is achieved through the international journal, *Risk Analysis*, which has its editorial office within the ORA. The editor-in-chief of *Risk Analysis* is also the coordinator of the ORA.

The long-term objective is to make the ORA a recognized national center of excellence in risk analysis with major focus on predictive toxicology, experimental risk analysis, and hazardous wastes. The ORA is a major contributor to the human health risk analysis initiative at ORNL through its laboratory and field programs. A growing acceptance of the application of risk analysis to

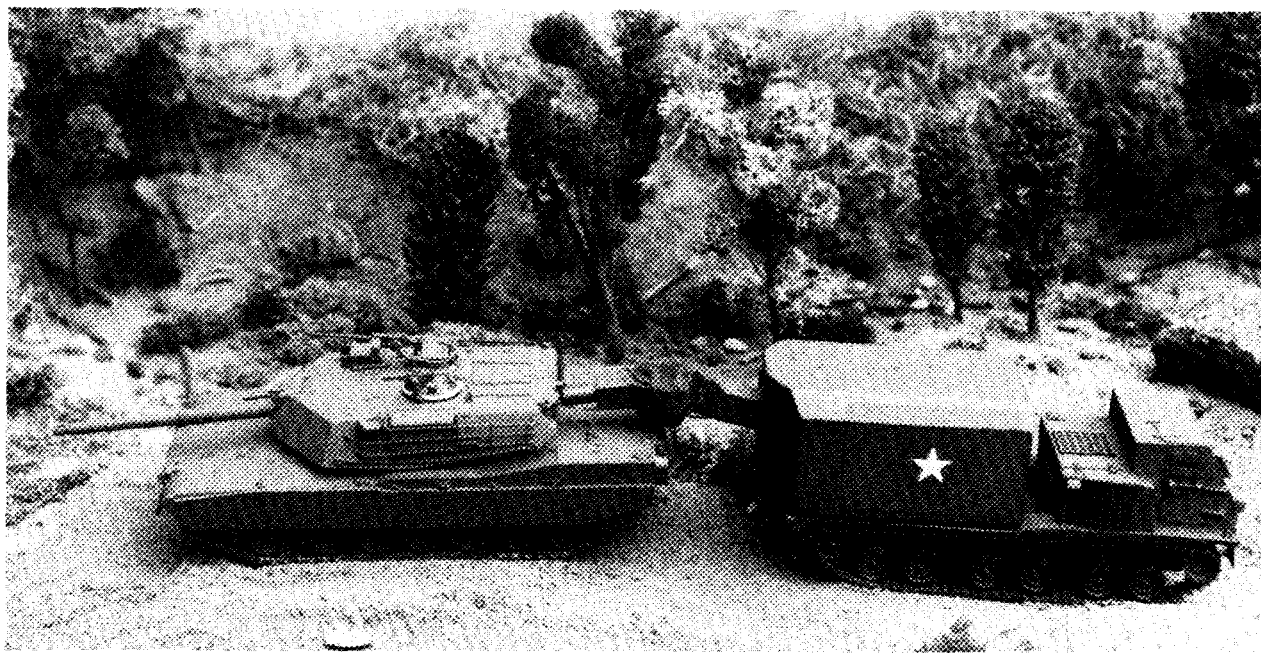


Fig. 44. Models depicting battlefield ammunition resupply for the Future Armor Rearm System (FARS) Project.

many types of energy-related regulatory and decision processes is expected to provide increased opportunities for the ORA.

Scientific and Technical Information Centers and Data Bases at ORNL

ORNL hosts a unique combination of technical proficiency, computer programming and processing capability, and information science expertise. With these resources, ORNL has established one of the most extensive and authoritative complexes of scientific data and information analysis centers in the United States. Today, ORNL has more than 200 textual and/or numeric data bases covering various technical disciplines in support of DOE and WFO (non-DOE federal and state agencies).

The development of many of the technical data bases at ORNL follows a similar pattern. A specific scope is defined; comprehensive literature collection, data evaluation, and processing are done; quality assurance by an external review panel is frequently sought; and finally, access to the user is made available through modem or direct connection. Brief descriptions of some selected information centers and data bases follow.

Radiation Shielding Information Center The Radiation Shielding Information Center (RSIC) was established in 1962 at ORNL. Founded to serve as an information analysis center (IAC), RSIC follows guidelines and goals suggested by the Weinberg Panel of the President's Science Advisory Committee, which recognized the important role that IACs could serve in meeting the technical information needs of modern society in the face of the "information explosion." The center provides in-depth coverage of the radiation transport field and is able to serve the needs of a variety of disciplines on an international basis. RSIC staff members collect, organize, evaluate, and disseminate technical information about shielding and protection from the radiation associated with fission and fusion reactors, weapons, outer space, accelerators, medical facilities, and nuclear waste management. The center continues to be a leader in recognizing the role that computer codes and computer-readable data play in any technical discipline and has always treated such as valid technical information. As a result, the RSIC collections are a valuable resource of radiation transport computing technology. Staff members are on call to answer queries about radiation transport problems and to recommend solution strategies that draw on the technical resources available from the center.

RSIC has multiagency funding from DOE (AT—Magnetic Fusion; AF—Nuclear Energy R&D, AH—Remedial Action and Waste Technology, AJ—Naval Reactors, CD—Uranium Enrichment, DB—Nuclear Waste Fund, and GB—Weapons Activity); the Nuclear Regulatory Commission; and the Defense Nuclear Agency.

Carbon Dioxide Information Analysis Center CDIAC, an issue-oriented center, supports the needs of CO_2 research into potentially related environmental consequences such as the "greenhouse effect." Its data holdings include such diverse information as tree-ring chronologies, surface air temperature anomalies, atmospheric CO_2 concentrations, and CO_2 emissions estimates from fossil-fuel burning. Its user constituency comprises basic researchers generating and using raw data; those doing integrated assessments needing multidisciplinary, often derived data; and decision makers needing concise summaries of complex information.

An example of a data package produced by CDIAC is the Carbon Dioxide Emissions Data Base developed at Oak Ridge. Annual global and country CO_2 emissions and per capita emission rates from fossil-fuel burning and cement production are provided. This well-documented data set is the basis for projecting future atmospheric CO_2 concentrations and is used as input for global climate modeling. CDIAC's *Carbon Dioxide Newsletter* reaches 4600 researchers and decision makers in 140 countries.

CDIAC is sponsored by DOE's Carbon Dioxide Research Program.

Toxicology Information Response Center The Toxicology Information Response Center (TIRC) was established in 1971 to serve as an international center for toxicology and related information. TIRC provides information on individual chemicals, chemical classes, and a wide variety of toxicology-related topics for the scientific, administrative, and public communities. As an information analysis center, TIRC synthesizes comprehensive literature packages according to a user's specific request. Formats include, but are not limited to, custom searches of computerized data bases, manual literature searches, annotated and/or keyworded bibliographies, or written summaries of the literature. TIRC is sponsored by the National Library of Medicine.

ORNL Remedial Action Program Data and Information Management System The ORNL RAP Data and Information Management System (DIMS) was established in 1985 to support compliance with state and federal regulations mandating corrective actions at sites contaminated with radioactive and/or hazardous wastes. DIMS consists of three components: (1) the Bibliographic Data Base, (2) the Records Control Data Base, and (3) the Numeric Data Base. The Bibliographic Data Base and associated hardcopy reference collection serve as an index and repository for publications pertinent to the program. The Records Control Data Base serves as an index for retrieval of unpublished information generated by the program, such as correspondence, project plans, field notebooks, and chain-of-custody records. The Numeric Data Base serves as a central repository for technical data generated by the program and other applicable studies. Such data are used to evaluate the condition of the environment as it relates to ORNL's past waste-management practices and to justify decisions regarding corrective action. The categories of technical data include well-construction parameters, groundwater hydrology and quality, geology, soils/sediments, surface water hydrology and quality, meteorology, biological monitoring, and waste inventory.

Based on the data management experience gained for ORNL RAP, ORNL will play a key role in developing a consolidated data base for environmental data associated with remedial-action activities at all Energy Systems' facilities.

Remedial Action Program Information Center The Remedial Action Program Information Center (RAPIC) was established at ORNL in 1979 to serve the technical information needs of DOE's RAPs, which include SFMP, FUSRAP, and UMTRAP. RAPIC developed and maintains the Nuclear Facility Decommissioning and Site Remedial Actions Data Base, a comprehensive, centralized source of information concerning the scientific, technological, regulatory, and socioeconomic aspects of decommissioning radioactively contaminated facilities and associated site remedial actions. The data base currently contains 7000 records. Ten volumes of a bibliography entitled *Nuclear Facility Decommissioning and Site Remedial Actions, A Selected Bibliography* (ORNL/EIS-154/V1 through V10) have been published. In addition to the bibliographic data base, RAPIC developed and maintains the Remedial Action Contacts Data Base, which contains the names, addresses, telephone numbers, technical areas of interest, and program involvement for 1100 individuals involved in contaminated site remediation. RAPIC publishes an annual directory from this data base. RAPIC staff members are available to respond to all requests for technical assistance received from DOE Remedial Action Program staff and contractors.

Environmental Mutagen Information Center The Environmental Mutagen Information Center (EMIC) was started in 1969 for the purpose of collecting and analyzing experimental data from papers reporting on the evaluation of chemical agents for genotoxicity. As of September 1989, EMIC has indexed more than 73,000 papers reporting on more than 21,000 chemicals.

In 1979 the U.S. EPA Genetic Toxicology program was started using EMIC's collected data

file as the basis for its continuing review of short-term tests for genetic toxicology. These data were subjected to strict guidelines for data acceptability, and all evaluations were subjected to review by appropriate panels of experts. The resulting Gene-Tox Data Base contains peer-reviewed evaluations on more than 4000 chemicals evaluated in one or more of 73 short-term bioassays for genotoxicity. This data base provides information allowing correlation between chemical structure and genetic activity.

Information from the EMIC file and the Gene-Tox Data Base is incorporated into considerations for regulatory action and is included in the publications of the International Agency for Research on Cancer. EMIC is sponsored by EPA, the National Institute of Environmental Health Sciences, and the Agency for Toxic Substances and Disease Registry; Gene-Tox is sponsored by EPA.

Chemical Unit Record Estimates To develop guidelines and limits for controlling chemical substances by a valid scientific approach, various offices within EPA gather and evaluate information and prepare assessment reports. In 1988, the design and implementation of a comprehensive data base, the Chemical Unit Record Estimates (CURE) Data Base, was begun by EPA's Office of Health and Environmental Assessment (OHEA) and ORNL to communicate this information within the agency and facilitate the chemical regulatory process.

The staff of the Biomedical and Environmental Information Analysis Program has compiled and verified data from a wide range of OHEA documents. CURE is currently comprised of five subfiles: a chemical dictionary, a bibliography file, an experimental data file, a central summary file, and a comment file. There are currently 1900 chemicals in the chemical file, all of which have been classified according to the structural categories developed in the EPA Gene-Tox program. This unique data base will now provide a basis for structural activity to span both genetic toxicology, low dose toxicology, and carcinogenicity. A PC version of selected information from the mainframe file has been developed and is currently being tested within the OHEA. This multifunctional data base will provide EPA scientists and managers with administrative and chemical tracking information, raw experimental data, and evaluated values of risk assessment parameters to facilitate the process of chemical regulation.

Material Safety Data Sheet File The Material Safety Data Sheet (MSDS) File is a factual, nonbibliographic, referenced data base designed for use in the field by both nontechnical employees and professional industrial hygienists. As such, the information is technically accurate and comprehensive but written in layman's terminology. It complies with OSHA Hazard Communication Standard 29 CFR 1900.1200 and the Superfund Amendment Reauthorization Act, Title III, "Community Right to Know." There are 10 categories of information containing 74 data elements, most required by law. The data are compiled from manufacturers' material safety data sheets and a core set of standard references. Specialized safety, fire, and protective equipment information is added by appropriate experts. The MSDS File is subjected to peer review.

The MSDS File is being built, updated, and maintained at ORNL on an IBM main frame 3033 using the INQUIRE data base management system with an interactive menu-driven retrieval system allowing full or partial record browsing. Additional general employee access to the MSDS File has been developed, using the Video Tex (VTX) System. Information is organized by chemical compound and includes records on approximately 2600 generic chemicals and an additional 5000 trade name products. The MSDS File is used by Energy Systems facilities and other DOE national laboratories. The MSDS File is sponsored primarily by Energy Systems and has been supported by the DOE Toxic Materials Advisory Committee.

Human Genome Management Information System The Human Genome Management Information System (HGMIS) was inaugurated in March 1989 and has completed a very successful

year. The HGMIS was established to serve as a primary information resource for DOE's Human Genome Program. As part of its work, HGMIS has produced a quarterly newsletter, established an electronic bulletin board, and prepared two reports. One of these reports reviews the instrumentation currently used and that proposed for use in the DNA sequencing effort; the other publication is DOE's program report for 1989–90. The work of the HGMIS has provided DOE's Office of Health and Environmental Research with one of its first opportunities to draw attention to its role in the overall effort within the United States to map and sequence the human genome. As a result of its successful work with DOE, the National Center for Human Genome Research (NCHGR) at the National Institutes of Health has joined DOE in support of HGMIS for the purpose of producing a joint DOE/NCHGR bimonthly newsletter. The first issue of this joint publication was distributed in April 1990 and is called *The Human Genome News*. In addition, *Radon Research Notes*, in support of the DOE Office of Health and Environmental Research, Radon Research Program, has been initiated.

Information Management The Information Management area has developed desktop publishing techniques for several outreach applications, which include preparing newsletters, composing course manuals, developing a drinking water regulations poster, preparing and updating reference books on legislation, and composing questionnaires. A PC-based expert system, called NERC (for "NEPA Environmental Review and Compliance") is under development for the Environmental Monitoring and Compliance Section of the ORNL Environmental and Health Protection Office. NERC is used in preparing documentation of compliance with NEPA requirements and other applicable federal, state, DOE, and ORNL ES&H standards. Additional expert systems include (1) Air Permit Regulations and (2) Determination of RCRA/CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) Compliance.

Work for Others

In recent years, the work undertaken by ORNL for other federal agencies and organizations outside of DOE and NRC has grown to a significant portion of the Laboratory's total budget—about 20% of the total—and accounts for an increasing proportion of its overall R&D effort as well (Table 42). In light of these developments, the Laboratory has placed a new emphasis on management and coordination of WFO. In January 1990, a new programmatic office for WFO was created to coordinate these broad-ranging efforts more efficiently and to develop new WFO projects, while ensuring that work is consistent with ORNL's DOE missions and augments ORNL's research capabilities. The new programmatic office for WFO does not include responsibility for work done on behalf of the NRC, which remains under ORNL's NRC programmatic office.

A report on current and proposed WFO projects for the next 5-year planning period follows. The text is organized by sponsor or agency. These WFO technical projects are consistent with the DOE mission and the programmatic objectives of the Laboratory.

A significant portion of the ORNL WFO program involves collaborative work with DOE programs. The most significant example is the Space Defense Initiative Program, jointly funded by DOD and DOE. In addition, several of the Laboratory initiatives (see Initiatives section) involve support from other federal agencies or nonfederal sources. In the last few years, several cross-cutting issues in the WFO program have become apparent. In the future we propose to focus the WFO program on emerging national issues, such as global environmental change, international energy development and environmental protection, advanced materials development, advanced computing, waste management R&D, advanced imaging and signal processing, transportation systems modeling and efficiency, advanced energy technologies, molecular

Table 42. Work for Others program resource summary[a]
[$ in millions—budget authorization (BA)]

	1989	1990	1991	1992
Federal organizations				
Nuclear Regulatory Commission	15.9	17.2	17.7	18.3
Department of Defense	42.4	49.8	73.7	76.2
National Aeronautics and Space Administration	2.4	2.1	3.2	3.5
Department of Health and Human Services	4.8	4.8	3.7	3.9
Environmental Protection Agency	4.3	3.8	3.6	4.8
National Science Foundation	0.5	1.0	1.0	1.0
Federal Emergency Management Agency	1.2	2.2	2.6	2.0
Agency for International Development	1.1	1.3	1.5	1.6
Department of the Treasury	0.1	0	8.0	2.3
Other federal agencies	2.3	3.3	3.3	3.4
Nonfederal organizations				
Electric Power Research Institute	3.6	1.7	2.0	2.0
Other nonfederal organizations	13.6[b]	4.2	4.0	4.0
Total	92.2	91.4	124.3	123.0

[a]Applied Technology Division included beginning in FY 1990.
[b]Includes Isotopes Program.

biology, environmental risk analysis, and advanced socioeconomic modeling.

In 1988, the Oak Ridge K-25 Site's ATD joined the Laboratory to combine ATD's materials and manufacturing technology strengths with related technology development strengths at ORNL. ATD had been charged by DOE UE to transfer technology from the UE program to other federal agencies (e.g., DOD and NASA) and to the private sector. Examples of technologies being transferred include: polymeric composites; remote/noncontacting precision measurements using lasers and fiber optics; unique, compact precision data acquisition and analysis systems; high power-to-weight ratio motors and generators with the associated power and electronic control systems; high-speed centrifugal separation for isotope enrichment, gas purification, and gas detection; reliability and life prediction and assessment; and manufacturing science and technology, primarily in polymeric composite materials. Special initiatives include the "Thermoplastics for Space" and "Thick Composites in Compression" workshops that attracted over 500 attendees from academia, government, and the private sector in 1989.

Federal Organizations

While it is expected that ORNL funding from DOD will hold at present levels or decline somewhat in the coming years, funding from nondefense federal agencies, such as NASA, EPA, and the U.S. Department of Agriculture (USDA), may increase. The following is an agency-by-agency description of the proposed work.

Nuclear Regulatory Commission

Current ORNL efforts for NRC reflect the commission's priorities, public attitudes requiring a high degree of confidence in the safety of nuclear power, and the maturing of the current generation

of U.S. nuclear reactors. Completion of the more than 100 nuclear plants ordered in the 1960s and 1970s, coupled with the upcoming expiration of operating licenses for many of these plants, has shifted the NRC's research emphasis towards structural and component safety issues, structural aging research, reactor operational data analysis, advanced instrumentation and diagnostics, accident sequence analysis, and license extension requirements. Continued restrictions on the NRC research budget have resulted in time extensions for some programs and increased cooperative research with other countries in areas such as severe core-damage accident research. ORNL funding from the NRC has increased slightly in FY 1990 and is expected to remain reasonably stable or to increase slightly over the next several years. Greater NRC and ORNL budgetary increases could occur if issues such as the elimination of generation overcapacity and public concerns over environmental issues relating to fossil-fuel-based electricity production result in renewed interest and activity in the nuclear energy area.

ORNL performs work primarily for four offices within NRC: the Office of Nuclear Regulatory Research (RES), the Office for Analysis and Evaluation of Operational Data (AEOD), the Office of Nuclear Reactor Regulation (NRR), and the Office of Nuclear Material Safety and Safeguards (NMSS). RES, the major sponsor of ORNL activities, conducts comprehensive research programs that lead to regulatory guidelines and standards issued by the commission. NRR is charged with implementing regulations dealing with licensing and inspection of the commercial nuclear industry. These regulations are based primarily on knowledge obtained from the research programs. AEOD collects, analyzes, and evaluates operational safety data to identify areas requiring NRC or industry action. NMSS is charged with overseeing public health and safety licensing activities in the nonreactor nuclear area.

Nuclear Regulatory Research Research is expected to increase over the planning period in the areas investigating long-term behavior of reactor pressure vessels and those relating to extension of the operating licenses of existing power plants beyond their original 40-year period, including research into the aging characteristics of plant components. For example, Fig. 45 shows an instrument recently developed by ORNL staff members that will greatly improve NRC's ability to externally monitor the degradation of motor-operated systems in nuclear power plants. ORNL

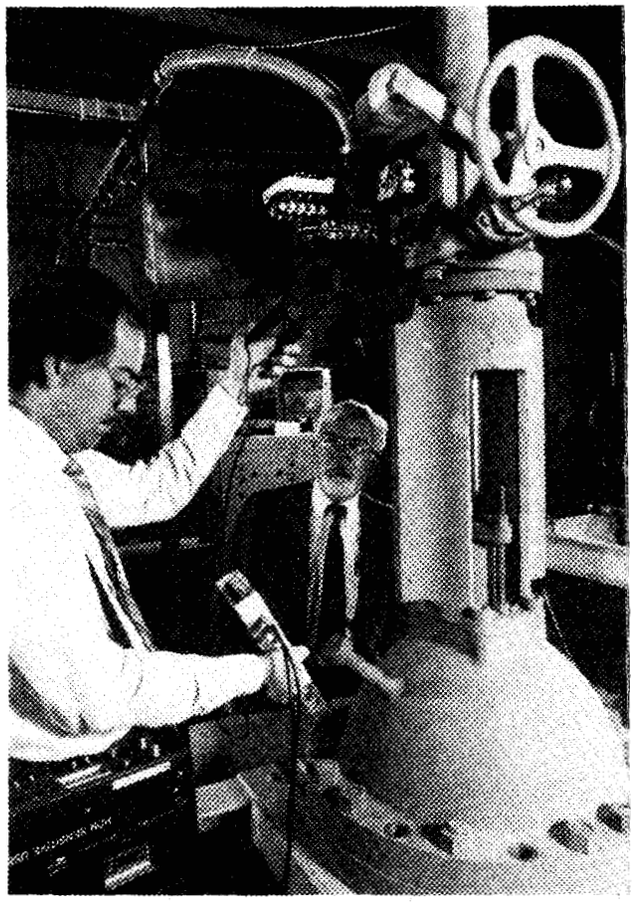


Fig. 45. David M. Eissenberg (right) and Howard D. Haynes of ORNL are shown demonstrating the device they developed to assist the NRC in externally monitoring the condition of electrical motor-driven systems, such as motor-operated valves, in aging nuclear power plants. The device enables operators to perform current signature analyses that give indications of system degradation or wear. Three companies have been granted nonexclusive licenses for commercial production of the new instrument.

efforts studying fission product behavior in severe accident conditions have produced the world's best data in these areas, but the work has declined somewhat as various issues are resolved. Some new related work has recently been authorized at the Laboratory to determine possible modifications of the portions of NRC Regulatory Guides 1.3 and 1.4 that deal with iodine chemical forms in containment. There are other research initiatives at ORNL relating to boiling water reactor (BWR) core-melt progression and in-vessel strategies for severe accident conditions.

Staff of the Heavy-Section Steel Technology Program were recognized by the NRC in January 1990 for 25 years of continuous outstanding research accomplishment (see Fig. 46). A Certificate of Appreciation was presented to ORNL, noting that this is the NRC's largest and longest-running research program and that the research results remain a standard against which new international pressure-vessel data are evaluated. During FY 1989, this NRC research effort to resolve issues and develop standards relating to reactor pressure-vessel integrity was reorganized into two programs: Heavy-Section Steel Technology, emphasizing fracture mechanics testing and standards development research, and Heavy-Section Steel Irradiations, emphasizing irradiation effects on structural steels. ORNL's efforts to provide materials embrittlement data are expected to continue to have high priority at NRC.

ORNL is also assisting NRC with the development of generic environmental impact documents appropriate for license renewal

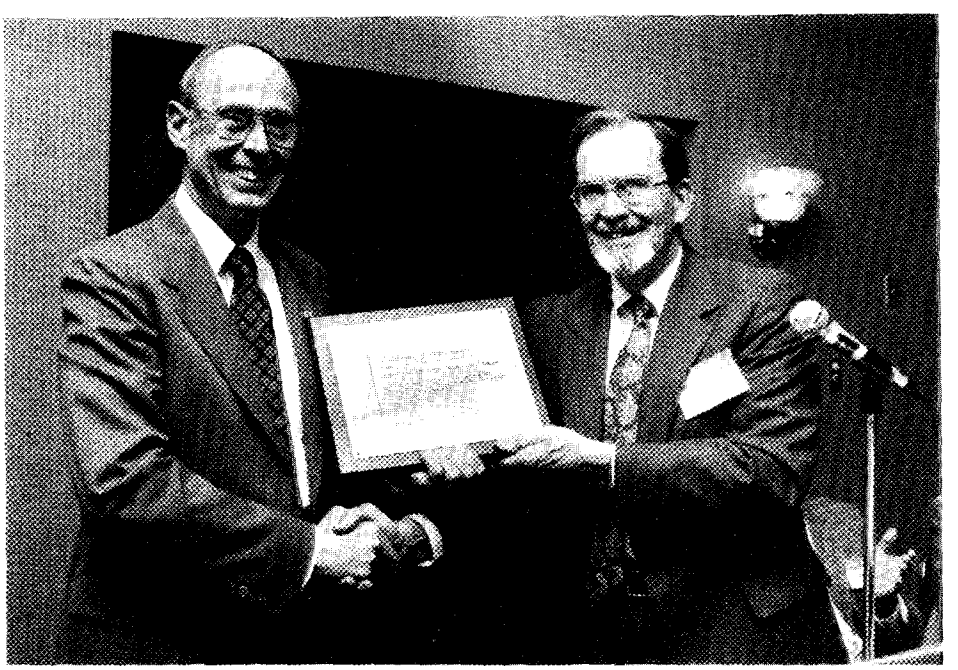


Fig. 46. Donald B. Trauger (left) accepted, on behalf of ORNL, an NRC certificate of appreciation for "25 years of outstanding research accomplishment" in the Heavy-Section Steel Technology Program. This NRC-sponsored work at ORNL has helped establish safety guidelines for the operation and regulation of U.S. commercial nuclear power plants and has provided the basis for worldwide nuclear reactor safety standards. Making the presentation is C. Z. Serpan, chief of the Materials Engineering Branch of the NRC Office of Nuclear Regulatory Research.

rulemaking. Collaborative research efforts are under way with the Sandia National Laboratories and seven foreign nations to develop and validate computer codes for modeling fission product behavior and core-melt progression under severe accident conditions.

Exploratory discussions have been initiated with ten European nuclear power research and regulatory organizations, with the objective of establishing joint sponsorship and cooperative research at the ORNL Pressure Vessel Research Users' Facility, which is centered around a full-scale nuclear reactor pressure vessel (Fig. 47). On the basis of a technical mission survey conducted by ORNL, priority will be given to investigations in the areas of flaw characterization, in-service inspection methods, in situ reactor vessel annealing, and vessel weld-repair technology.

The *Nuclear Safety Journal*, edited and coordinated by ORNL staff, was recently recognized by Secretary of Energy Admiral James D. Watkins for completing 30 years of publication in the nuclear safety arena (Fig. 48). NRC Chairman Kenneth Carr also sent a congratulatory letter and praised the publication for "outstanding contributions to the development of safety standards for the entire nuclear industry."

Analysis and Evaluation of Operational Data The single largest activity being conducted at ORNL for AEOD involves operation and maintenance of the Sequence Coding and Search System (SCSS), a computer-based system designed to increase the usefulness of the descriptive text contained in Licensee Event Reports. A new program, which uses SCSS data, involves the analysis of cause and corrective action data for use as programmatic performance indicators; this program has increased slightly in FY 1990.

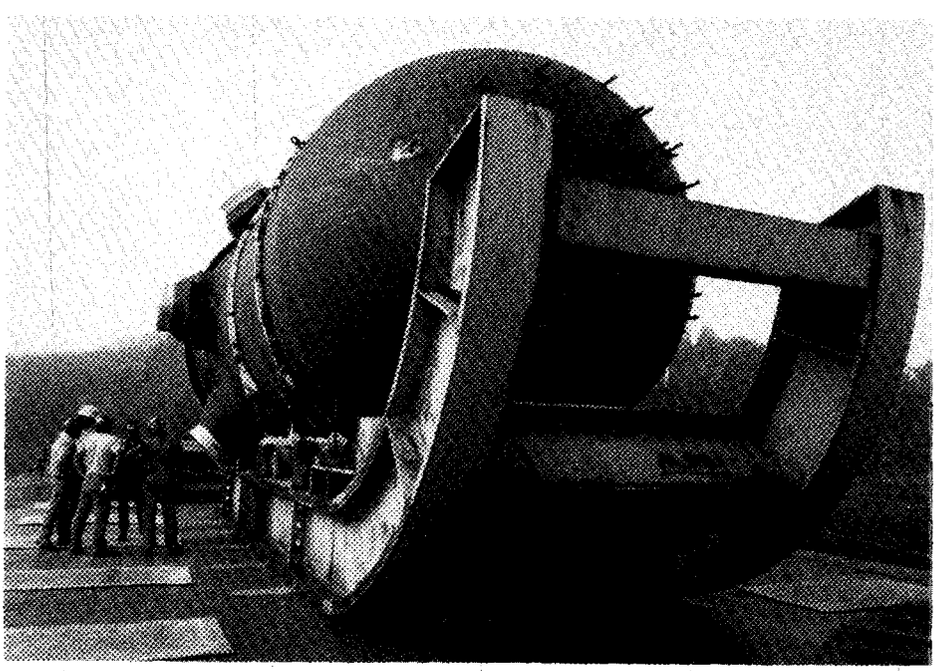


Fig. 47. This complete reactor pressure vessel from a canceled 1100-MWe nuclear power plant is shown on the barge used to transport it to ORNL for use in the Pressure Vessel Technology User's Facility. The 500-t vessel and head will be the focus of collaborative research on pressure vessel integrity issues. Initial efforts will include detailed characterizations and maps of the manufacturing flaws in the vessel, using state-of-the-art instrumentation and inspection techniques.

Fig. 48. In January 1990, Associate Laboratory Director for Nuclear Technologies, Alex Zucker (right), presented a commemorative plaque to Ernest G. Silver, editor of the *Nuclear Safety Journal*, marking the journal's 30th anniversary of continuous publication. The plaque holds a letter of commendation from Secretary of Energy Admiral James D. Watkins, extending his "earnest congratulations and thanks for a job well done" to the staff and contributors of *Nuclear Safety*.

Nuclear Reactor Regulation Using expertise developed in RES programs, ORNL provides technical consultation and assistance to NRR. On-call assistance is currently provided in the interpretation of nondestructive evaluation data, in analyses of fuel stability, in the review of licensing documentation, in evaluation of BWR stability phenomena, and in failure modes and effects analysis. A significant effort also involves investigations of the thermal-hydraulic stability phenomena of BWR cores or fuel assemblies. Funding has increased slightly in FY 1990 and is expected to remain stable or increase slightly over the planning period.

Nuclear Material Safety and Safeguards A new ORNL initiative in the area of licensing enrichment facilities was begun late in FY 1989. A new activity to review terminated materials license files is expected to begin by early FY 1991. This activity will help the NRC ensure that facilities with terminated licenses were properly decontaminated and pose no threat to public health and safety. Funding is expected to remain relatively stable over the planning period.

Other Offices The Laboratory provides technical assistance in the conduct of inventory verification, analysis of special nuclear materials samples, preparation of site-specific material standards, and review of environmental assessments and operating procedural changes.

Department of Defense

ORNL carries out R&D for the major DOD services—U.S. Army, Navy, Marines, and

Air Force—as well as for joint agencies such as the Defense Nuclear Agency, the Defense Advanced Research Project Agency (DARPA), SDIO, and the U.S. Transportation Command (USTRANSCOM). Several projects are managed by non-ORNL Energy Systems organizations (see following section, "R&D Contributions for WFO Managed by Other Oak Ridge Facilities").

Army ORNL research for the Army includes programs in materials science and technology, instrumentation and control systems, robotics and intelligent systems, man-machine interface technology, transportation systems, operations research, and environmental analysis.

ORNL's program with the U.S. Army Laboratory Command (LABCOM) has expanded significantly and now involves the transfer of DOE technologies to several LABCOM agencies. These programs focus on ORNL's unique capabilities in advanced materials and robotics, and they also include basic and applied science. LABCOM has proposed a major initiative to establish a 5-year collaborative research program with all DOE laboratories beginning in FY 1991. Oak Ridge staff have helped provide the leadership in planning this cooperative program with the Army.

Work has also been initiated with the new DOD Special Operations Command (SOCOM). These programs are focused on using ORNL sensor and instrumentation technologies in SOCOM programs directed at drug interdiction, guerilla warfare, and special operations. These activities are expected to expand and will be funded jointly by DOE and SOCOM and other military agencies in FY 1991 and beyond.

Work will continue on the major research initiative concerning the aging of materials used in Army munitions stockpiles. This project is under the aegis of the Armament, Chemical and Munitions Command. Also, work will continue in advanced materials R&D, taking particular advantage of ORNL's well-recognized expertise in composites, ceramics, carbon/carbon bonding, intermetallics, and related technologies. Research will begin on mathematical and computational modeling of crack propagation in materials using nondestructive evaluation procedures. These projects are designed for the development of advanced armor and shielding, as well as lighter-weight components for increased mobility of weapon systems and vehicles. In addition, work continues on advanced materials for reentry vehicles and space applications for the Space Development Command.

Other recently launched initiatives, which are continuing to expand, deal with advanced instrumentation and robotics and intelligent systems technology, including advanced robotics concepts for LABCOM and related prototype applications for the Army's Human Engineering Laboratory, Ft. Belvoir Research and Development Center, and other related agencies. New programs in laser and communications technology for the battlefield are also planned.

ORNL continues to support major environmental assessments. ORNL is assisting the Army's Program Manager for Chemical Demilitarization to prepare site-specific environmental impact statements for the on-site disposal of chemical agents and munitions stored at eight continental U.S. locations and one non-U.S. location (Johnston Island in the Pacific Ocean). ORNL is also assisting the Army in assessing the impacts of destroying the U.S. European stockpile of chemical munitions at the Johnston Island disposal facility. ORNL is also providing support in the development of enhanced response plans for installations that store chemical agents and munitions. For the Installation Restoration Program, ORNL is assisting the Army's Toxic and Hazardous Materials Agency on scientific and regulatory issues and in defining cleanup criteria for hazardous waste sites. The Army has many waste sites throughout the country that must be remediated according to EPA policies and guidelines. ORNL scientists are using their knowledge of EPA's regulations and risk assessment strategies to define the necessary cleanup criteria for the Army.

ORNL will expand its environmental analyses of the potential impacts of changing military operations or broader programmatic missions at specific sites. This work includes

developing new environmental measurement and analytic techniques for laboratory and field applications. Work is also expanding in analytical chemistry and environmental technology to characterize chemicals (such as military fuels) and their by-products and to develop biological indicators for environmental and health assessments.

R&D for the Army in operations research and transportation systems, energy conservation, energy security, fuels research, and advanced engineering continued to expand. Included among these projects were the development of prototype telecommunications systems and a model for the coordination of routing and scheduling military convoys over the U.S. highway system. Research to develop regional economic assessment decision support systems for recruiting and for force structure analysis for the National Guard Bureau (NGB) is expected to grow moderately over the planning period. ORNL is providing analytical techniques to NGB for force structure and mobilization planning and related civilian missions.

In addition, under the sponsorship of the Military Traffic Management Command (MTMC), ORNL is developing a proof-of-concept prototype, called Integrated Booking System—Prototype (IBS-P), designed for the selection of ocean carriers to move military cargo. ORNL is defining the requirements for a shared data environment for the target IBS. In another project ORNL is also designing and prototyping a decision support and executive information system for the MTMC Personal Property Directorate.

Navy and Marine Corps ORNL conducts research for the Navy and Marine Corps in engineering systems, instrumentation, data systems, reliability and maintenance, materials R&D, fuel supply and use, diesel testing, energy conservation, and waste disposal.

ORNL's Navy Mobility Fuels Forecasting System has been used to estimate the availability and quality of Navy fuels for future-year business-as-usual and petroleum supply disruption scenarios originating in the Persian Gulf and other world regions. ORNL is planning to use the forecasting system to analyze the impacts of democratization of Eastern Europe and related events.

ORNL plays an important role in instrumentation and engineering R&D for the David W. Taylor Research Center (DTRC). The DTRC is the Navy's primary research, development, test, and evaluation center for Naval vehicles. Two primary areas of interest to DTRC are ship and submarine silencing and methods to design and test high-strength hulls and components. ORNL assists the DTRC in the design and development of R&D instrumentation systems for experimental models of proposed submarine designs, the development of new ship and submarine designs, and support for the current fleet. In addition to this work, ORNL continues to evaluate new technologies for the Navy's advanced submarine R&D program, which is planned to support the new emphasis on Defense Advanced Research Projects Agency (DARPA) and the Navy.

For the Naval Air Systems Command, ORNL research involves the design and evaluation of advanced part-task trainers for Navy missile systems. Issues related to the ability to ensure high levels of training effectiveness and the relationship between trainer fidelity and human performance are key concerns involved with appropriate mental models, and subsequently, effective trainer interface design.

R&D continues also on instrumentation and equipment reliability and maintenance that will explore methods to determine optimal times for preventive maintenance. ORNL research also involves Productive Base Analysis which addresses the capability of U.S. industry to produce defense material in a time of war. Research continues on new techniques to modernize naval systems, especially in the areas of logistics, mobilization planning and modeling, command and control, marine telecommunications, environmental technology, computer-aided instruction, and robotics and intelligent systems.

For the Navy Underwater Systems Center (NUSC), ORNL will use the Injection into Microwave Plasma quadrupole superconducting

magnets to construct a long dipole field to be used in propulsion experiments at NUSC.

Other projects include electronic component design cost-effectiveness, life-cycle analysis, and prototype development for the Naval Sea Logistics Center; a computer-aided analysis research project for the Naval Sea Systems Command.

Air Force For the Air Force, ORNL performs research on environmental systems, advanced materials R&D, advanced fuels research, data systems, waste management, environmental research, and other related activities.

A major economic analysis activity supports the Air Force Engineering Services Center (AFESC) and the Air Forces Major Commands. ORNL performs economic analysis and technical support for evaluating the use of private-sector financing to augment government funding to achieve a more rapid delivery of new facilities and services. Other support to the AFESC includes the evaluation of Air Force base energy requirements to assess whether energy requirements can be met cost effectively by increased coal consumption.

In support of DOD's Installation Restoration Program (IRP), ORNL is assisting the Air Force's toxicology program at Wright-Patterson Air Force Base. An extensive update and revision of the original three-volume IRP toxicology guide was completed. The resulting four-volume guide, covering 70 organic compounds, incorporated the latest available information on state and federal regulatory status, health hazard data, analytical techniques, environmental fate, and a wide range of toxicologic data, including carcinogenicity, genotoxicity, teratogenicity, and short-term and long-term exposure effects on humans and laboratory species. In addition, all of the data were incorporated into an on-line, relational data base using the ORACLE data base management system. The present work involves compilation, analysis, and presentation of similar information on a series of metals, comprising more than 80 individual compounds or salts that are of concern to the Air Force. This work was completed in November 1990.

For the WRDC, ORNL is performing research in multisensor integration (MSI) algorithms for hypercube computer architectures. Hypercube computer architectures offer supercomputer capabilities in a small volume, which are ideally suited for robots and satellites. This research augments and complements DOE robotics MSI research being carried out at ORNL. Also for WRDC, ORNL is working on the development and evaluation of thermoplastic materials for space applications, the development of design/analysis and fabrication techniques for thick composites, and the design and evaluation of foil-lined composites for cyrogenic environment applications.

A major environmental R&D activity will continue to support the Air Force Environmental Impact Analysis Process, which addresses both programmatic and site-specific analyses of Air Force actions. ORNL conducts environmental compliance assessments for major facilities of the Tactical Air Command and the Space Command.

Military Transportation One of the most successful WFO programmatic areas involves the R&D for the DOD transportation agencies. To coordinate this work with our other research in transportation systems, ORNL management created a new Center for Transportation Analysis. The center will blend together complementary work for DOE, DOT, and the various defense transportation agencies, linking such WFO sponsors as the Federal Aviation Administration, the Federal Highway Administration, the Military Airlift Command, the Military Sealift Command, the Military Traffic Management Command, and USTRANSCOM, among others.

ORNL's Center for Transportation Analysis is a primary resource for technical innovations to improve the utilization of DOD transportation resources. The center's staff has won wide recognition throughout the military for their broad range of contributions to increase the efficiency of both peacetime and wartime moves. Although most work to date has been in the area of scheduling and transportation analysis for USTRANSCOM and its three components, the Military Airlift

Command (MAC), Military Sealift Command (MSC), and Military Traffic Management Command (MTMC), FY 1990 efforts also supported transportation resource planning for Joint Staff logistics studies and for DARPA transportation planning research.

Center staff are now engaged in development of a comprehensive system that will help manage MAC's peacetime and wartime transportation missions. The peacetime portion of the system will help MAC schedule routine missions to meet shipping demands at minimum cost. The wartime portion of the system will support deliberate planning, the development of contingency plans during peacetime, as well as time-sensitive planning and operations support in times of crisis.

Work in FY 1990 for USTRANSCOM resulted in development of a microcomputer-based system for estimating strategic cargo and personnel flows of an overseas deployment. The system was used by the command's emergency operations center during the recent "Desert Shield" deployment. Earlier work by ORNL, Energy Systems Computing and Telecommunications Division (C&TD), and UT personnel resulted in a sophisticated sealift scheduler for MSC and continental U.S. traffic management prototype for MTMC. The sealift scheduler is designed so that the same algorithm can be used in MSC's large IBM mainframe and USTRANSCOM's microcomputer-based flow estimator. The MTMC deployment traffic management prototype is used to analyze transportation mode assignments and route military traffic to airfields and seaports during an overseas deployment.

Transportation Center staff are developing a system to assist MTMC with analysis of the effectiveness of DOD personal property moves. The system will be a pioneer in use of networked workstations and personal computers to implement a command-wide "corporate" data base. This work is a follow-on to an effort that implemented a wide-area data communications network between MTMC and shippers at Army installations throughout the country.

Defense Nuclear Agency ORNL is performing research for the Defense Nuclear Agency in support of the Human Response Program. This effort addresses the human factor in the military nuclear environment through models and data bases that predict the human response in all nuclear threat situations. The research is carried out through expert integration of state-of-the-art radiation transport and human response data.

ORNL is satisfying the conditions for this program as defined under the DOD Qualified Research Requirements documents through a multiphased plan that includes definition and analytic validation of the initial and protracted radiation environments, shielding calculations for tactical armored vehicles, and an extensive intercomparison between the existing and newly developed methods to assess radiation impacts on military vehicles and human beings.

In addition, an experiment is in preparation with force-flow cooled, cable-in-conduit conductors to determine the existence of thermal hydraulic quench back or the rapid quench of a superconducting cable under certain conditions of current density, magnetic field, and helium temperature.

The Defense Nuclear Agency also is supporting research at ORNL to define more accurately the effects of nuclear weapon radiation on the victims at Hiroshima and Nagasaki.

Strategic Defense Initiative Organization The SDT program in Energy Systems uses the unique military-assistance capabilities of all three Oak Ridge facilities (ORNL, the K-25 Site, and the Y-12 Plant). Work is currently being performed on neutral particle beams, lightweight power and energy-storage systems, optical components, survivability and shielding, flywheels, parallel computing and sensor integration, and lightweight structures made from high-temperature materials. The level of effort for the coming years will be heavily influenced by the national SDI policy set by the Bush administration. All indications are that funding cutbacks in the overall SDI program are likely in the future.

Several significant program changes are expected in the next few years in ORNL's SDI research. The SDI Survivable Optics

Manufacturing Operations Development and Integration Laboratory is a major SDI initiative that expanded in FY 1989. This program will continue to examine and integrate optical technologies into an overall fabrication process and examine the broad scope of the manufacturing system as opposed to the singular development of manufacturing subsystems. It will provide the integrated technology that, if implemented by private industry, would achieve the stated SDI optical component goals.

Two major ongoing programs in SDI are the optics development and shielding programs. Expertise and facilities available within Energy Systems for mirror fabrication, ion implantation, radiation testing, and optical characterization are being applied to the development of radiation-hardened, passive optical components. These components are of interest to SDI and, potentially, to other areas within DOD. Energy Systems capabilities are also being applied to develop shields to protect satellites against high-kinetic-energy particles, high-energy lasers, and particle beams as well as natural and man-made radiation.

ORNL staff members are performing an advisory role for the federal government as part of the technical advisory group on Superconducting Magnetic Energy Storage project.

Other Department of Defense Agencies

For DARPA, the Laboratory has initiated a project on AI for transportation planning research. Work will expand on R&D in advanced parallel computing for the Worldwide Military Command and Control Information Systems Program Office.

National Aeronautics and Space Administration

Much of the R&D ORNL performs for NASA is managed by non-ORNL Energy Systems orginizations. (See a following section, "R&D Contributions for WFO Managed by Other Oak Ridge Facilities.")

For NASA, ORNL is performing basic research to produce a conceptual design for equipment required to levitate and melt niobium in space. Basic research is required to substantially increase the efficiency of the rf generator and to design special water-cooled coils to levitate and heat metal samples suspended in space. The modular design concept is proposed to provide hardware that can be adapted for use by NASA principal investigators who are planning such experiments.

NASA funding is anticipated for ORNL to design and implement major components of global vegetation dynamic models, contribute to the formation of comprehensive earth system models, and consult in the design of remote-sensing satellites from the standpoint of model data requirements and application of vegetation models to interpret satellite imagery. We anticipate new initiatives addressing impacts of climate change on natural resources; support for joint research in mathematical, statistical, and computational methods is expected from NASA's global change program.

NASA's recent initiative to put man on the moon and Mars on a continuing basis will create an opportunity for ORNL to support the development of reliable space nuclear power systems for both electrical and propulsion applications. Work in this area is already under way and is expected to grow.

In other current work for NASA, ORNL is developing advanced high-temperature thermal storage technology using metallic phase-change media for advanced solar dynamic power systems. The effort includes modeling of system thermal performance and prototype development and testing. This work is an extension of thermal energy storage work being performed for DOE. NASA also provides funding for RISP, including robotic and human-system interface technology for space missions.

For the NASA-Lewis Research Center, ORNL will undertake the conceptual design of a number of magnet systems and provide the amount of conductors and approximate cost for each, as well as scaling rules that can be used to estimate other solenoidal magnets of the type designed. NASA through the Marshall Space Flight Center supports work on modeling and numerical simulation of binary alloy solidification processes.

The level of support for this work is expected to increase somewhat in FY 1991–1992.

A possible new initiative is the development of advanced thermal management techniques that will be required to meet system performance requirements for space applications. Components include radiators, heat pumps, and heat pipes. The thermal rejection components will be fabricated of highly conducting composites to meet mass restrictions. Advanced heat-actuated, low-maintenance heat pumps will be developed to improve system reliability and reduce system mass to the point required for space or planetary deployment.

Department of Health and Human Services

The Department of Health and Human Services (DHHS) supports research, in-depth literature evaluation, analysis, and data-base development in carcinogenesis, genetics, and toxicology. Its funding is expected to remain reasonably constant. The majority of DHHS funding is from the National Institutes of Health (NIH), with some funding from the Food and Drug Administration (FDA). Various branches of the NIH support ORNL's programs:

- National Cancer Institute (NCI);
- National Center for Toxicological Research (NCTR);
- National Institute of Environmental Health Sciences (NIEHS);
- National Heart, Lung, and Blood Institute;
- National Institute of Child Health and Human Development;
- National Institute on Drug Abuse;
- National Library of Medicine (NLM);
- National Toxicology Program;
- Agency for Toxic Substances and Disease Registry (ATSDR); and
- Office of the Inspector General.

ORNL is providing guidance for ATSDR on the performance of health assessments at hazardous waste sites on the Superfund List. Methodologies are being developed to predict acute and chronic health effects resulting from exposure to hazardous chemicals.

NCI is supporting a study of neoplastic changes in tracheal epithelial cells. A major change is in the response to the factors that induce cell differentiation; in this context, the role of TGF-a is being investigated. The response to this growth factor, and therefore its influence, changes as cells progress from preneoplasia to neoplasia.

Environmental exposures usually involve more than one carcinogen or toxic agent, yet little is known about the interactions of such agents. The development of a flow-through tracheal implant system has made it possible, with NCI funding, to study the effects on tracheal cells of mixtures of agents and sequential exposures at the molecular, cellular, and tissue levels.

For NIEHS, ORNL is enlarging the data base on the response of germ cells to chemicals. Gene-mutation and chromosome-aberration induction are being measured.

With support from NIEHS, the hypothesis that gene transposition is an important part of the mechanism of carcinogens induced by environmental agents is being tested. A mouse-model system is being used to investigate whether the mouse chromosomal long terminal repeats-containing retroviral gene elements are capable of initiating genetic transposition following the genotoxic injury of the cell.

The National Institute of Aging, the National Institute of Child Health and Human Development, and, indirectly, the National Institute of Alcoholism and Alcohol Abuse support projects for the cryopreservation of embryos of mice that have distinctive genetic properties.

Environmental Protection Agency

ORNL's EPA program addressed numerous health, environmental, and economic problems and issues, particularly research on the ecological effects of global change, toxic effects of pollutants associated with energy-production processes, waste disposal, and methods for environmental

monitoring and assessment. Health and environmental risk analysis and epidemiological studies continue to be important components of this work. ORNL is also involved in the development of biomarkers for assessing exposure and effects of environmental contaminants.

ORNL is continuing its evaluation of the economic viability of recycling solid waste, with emphasis placed on plastics recycling. In addition, work is under way on evaluating various economic incentive programs that might be implemented to promote additional recycling and source reduction of solid waste.

EPA is also supporting research at ORNL to evaluate the impact of municipal waste incineration on human exposure to pollutants through the terrestrial food chain. ORNL is developing a computerized terrestrial food-chain model to aid in this analysis.

Biologically based assessment of the human risk from exposure to hazardous chemicals involves a series of judgmental decisions concerning unresolved issues in risk assessment. ORNL staff, with EPA and NSF support, are developing biologically-based pharmacokinetic and pharmacodynamic methodologies to evaluate the scientific bases of these assumptions. Pharmacokinetic models predict chemical transport and metabolism across routes of administration, across species, and through temporal variations in time; pharmacodynamic models relate genetic mutation frequencies and cell-turnover dynamics to the epidemiology of cancer in animal and human populations. NSF is also providing support for this research.

A joint cooperative research project with EPA and private industry includes utilizing unique capabilities and facilities for testing thermal materials and systems. Products are being tested to evaluate the effectiveness in reducing heat gains and losses through low-sloped commercial roofs. New materials are being identified and tested to replace products produced with CFCs, which are being phased out as directed by the Montreal Agreement signed by 56 countries to reduce the risk to the ozone layer. Cooperative projects with EPA also include a study of advanced thermodynamic cycles for refrigerator/freezers using alternate refrigerants and a laboratory and field study of foam insulation with non-CFC blowing agents.

ORNL scientists are also assisting EPA with the development and evaluation of advanced spectroscopic methods for analyzing chemical pollutants.

ORNL scientists are evaluating and analyzing the literature and will prepare a variety of health and environmental summary and assessment reports for EPA. These include

- chemical hazard information profiles,
- reportable-quantity documents for carcinogenicity and chronic toxicity,
- health- and environmental-effects documents,
- reference dose/concentration profiles for oral and inhalation exposures, and
- report on reduced uncertainty in risk-assessment methodology development (less than life-time risk assessment).

Data-base development activities for EPA are expected to increase. CURE, an evaluated data base, is under development for OHEA. CURE will be an on-line interactive file to be used by EPA scientists and regional offices for performing chemical risk assessment. In addition, ORNL will continue to develop a peer-reviewed Genetic-Toxicology Database and Environmental Mutagen and Teratogen Information Center Files that are pertinent to performing chemical hazard assessment and conducting quantitative structure activity relationship studies. A novel technique developed in association with EPA's Health Effects Research Laboratory allows for the computer generation of graphic display of experimental data on single chemicals, groups of chemicals, and so on. These resources (toxicity data on more than 22,000 unique chemicals) are being used for the finding patterns among chemical and biological data. This effort represents one of the largest of its kind.

Acidic deposition research activities will continue to decline in FY 1991. Major emphasis is on the effects of acidic precipitation on forest and aquatic systems and on ion mobility in soils.

ORNL will increase its research and analysis support to EPA's Environmental Monitoring and Assessment Program in the areas of site characterization, biological indicators, biological markers, environmental risk, and technical integration. Continued support of EPA's critical loads research program is also anticipated.

EPA support is expected in four important analyses dealing with ecological impacts resulting from global climate change. The project will take four approaches to the problem of predicting biospheric response to global change: (1) assemble relevant data bases regarding the increase in trace gases in the atmosphere; (2) perform critical experiments regarding the direct effects of pollutants on tree species; (3) synthesize data, models, and experimental results to produce regional predictions of the direct and indirect effects of global change; and (4) simulate the global response of vegetation to climatic effects.

Research in advanced data systems continues for EPA's Office of Planning, Budget, and Program Management. This research will develop computer-analysis capabilities that will allow EPA to better formulate environmental regulatory policy and to analyze groundwater-contamination problems. Although research on ecological risk of chemicals declined in FY 1990, an increase in this area is expected in 1991.

In addition, ORNL is participating in the development of EPA's new climate change initiative and will continue to expand its work for the Office of Emergency Response and Waste Management to help develop modern computerized information management systems in support of RCRA and CERCLA.

ORNL provides technical support to EPA Region IV programs, such as restoration and remediation of sites in the southeastern United States listed on the National Priorities List. Work is ongoing to evaluate the adequacy of existing emergency-response systems in the vicinity of chemical plants. In addition, research in physiological pharmacokinetic models, which aids in low-dose extrapolation, continues for EPA's Carcinogen Assessment Group. ORNL is also analyzing environmental issues and opinions for the Office of the Administrator.

National Science Foundation

ORNL is expecting some growth in the overall amount of funding provided by NSF in the next several years, particularly in those areas where the Laboratory has either unique capabilities or where basic research is not supported by DOE programs. Discussions are in progress to assist NSF in promoting educational training for the sciences.

Because of its unique position as a leader in systems and theoretical ecology, ORNL plays a strong role in these fields and works closely with various universities. NSF recognizes ORNL's leadership in ecosystem research and global terrestrial carbon cycling, and provides support for the study of nutrient cycling and ecosystem resilience. This project continues to develop and experimentally test food-web simulation models to evaluate the resiliency of stream ecosystems to disturbances. ORNL will continue to explore its potential contributions to the planned U.S. Department of Interior-NSF-DOE interagency Continental Drilling Program. Another research effort sponsored by NSF involves development of a fiber-optic-based fluoroimmunosensor (FIS), an instrument using monoclonal antibodies and laser-induced luminescence for the detection of trace levels of biological species in body fluids. Additional research is expected to include mathematical and statistical methods for data analysis.

ORNL is providing technical assistance to the Division of Polar Programs in their effort to evaluate the environmental impacts of U.S. activities in Antarctica. ORNL will prepare a programmatic environmental impact statement as well as several site- and project-specific environmental impact assessments. Emphasis is being placed on waste and fuel management, sensitive resources, and global concerns for the pristine Antarctic environment.

Federal Emergency Management Agency

DOE and its predecessor agencies have been providing major research support to the Federal

Emergency Management Agency (FEMA) and its predecessor agencies from more than 35 years. Current ORNL programs for FEMA include a range of research, development, and technical assistance activities in support of national preparedness for major emergencies. At FEMA's request, ORNL serves as an independent center of expertise in areas ranging from engineering assistance to analysis and assessment. Engineering work includes assisting in hardening civil defense installations against electromagnetic pulse effect, development of devices that protect against the effects of electromagnetic pulse, and testing equipment.

Analysis and assessment activities include building economic models of preparedness options, assisting with the use of computer graphics, studying human behavior in emergencies, and working on state-of-the-art assessments on various programs and issues. These activities will also include the following issues:

- development of National Infrastructure Information System;
- emergency preparedness to hazardous material accidents, including those involving chemical weapons;
- impacts of disasters;
- postdisaster economic recovery;
- data sources for emergency management;
- shelter concepts for emergency protection;
- civil defense program planning;
- evacuation planning for natural and man-made disasters;
- public alert/notification system performance;
- preparedness for special populations and institutions; and
- adequacy of training for emergency workers.

These programs are expected to remain stable, as shown in the resource projections, at levels that reflect current agency guidance.

Agency for International Development

ORNL serves as a center of expertise for the Office of Energy's AID on technical aspects of energy planning and energy technology applications for developing countries, with emphasis on global energy efficiency improvement and environmental management. ORNL's work includes research, analysis, and information dissemination. In addition, ORNL provides technical assistance in the following areas:

- project development;
- implementation planning;
- evaluation related to energy planning;
- renewable energy technologies; and
- environmental impacts of climate change.

Department of the Treasury

Since 1984, multidivisional ORNL projects involving manufacturing automation, quality assurance, and counterfeit deterrence have been sponsored by the Bureau of Engraving and Printing, a branch of the Department of the Treasury. The focus of the research is the integration of new technology into the manufacturing of U.S. currency and postage stamps. Quality assurance and control through on-line applications of machine inspection are emphasized using machine vision and specialized sensors. Two prototype high-speed machines are being developed in collaboration with industry. The first prototype, the Web Currency Inspection System, is designed to implement the ORNL flaw severity model, which provides quantification for human perception of printing flaws. The system will examine rolls of printed currency at web speeds up to 600 ft/min and mark the defective notes. The second prototype, the Web Stamp Inspection System, uses specialized sensors to inspect special features of postage stamps at web speeds up to 600 ft/min. Technical support is being provided to the Bureau in a joint development of the Web Currency Finishing System (WCFS). The WCFS will print and inspect currency seals and serial numbers, cut the rolls of printed paper into notes, and package the notes that passed machine inspection. Research associated with the engineering development includes human vision analysis, color measurements, high-speed image analysis, alternate

printing methods, and manufacturing systems analysis.

Department of Transportation

ORNL's Center for Transportation Analysis, funded by the Department of Transportation, covers all transportation modes, with particular attention to highway transportation, which accounts for more than 73% of the nation's energy used on travel. ORNL is assisting the Federal Highway Administration (FHWA) in research areas that include development of freight and passenger demand models; assessment of data quality and data consistency of highway statistics; design of sampling models and estimation procedures to provide needed information for policy formulation and policy impact studies; development of data collection methods and advanced data management systems to improve data integrity and availability; analysis of nationwide surveys to address issues in current or future national transportation policies; development of methods to statistically link data sources to study inter-modal traffic, and research on intelligent vehicle and highway systems.

In response to FHWA's 1990 National Transportation Policy, research effort provided by ORNL is increasing in several areas. First, ORNL is developing procedures to estimate the private sector's contribution to the nation's highway infrastructure. Second, ORNL is assisting FHWA to study the relationship between truck accidents, highway geometric design, and truck performance characteristics. Results from this study will guide how highways will be designed to more safely accommodate heavier trucks in the nation's highway system. Third, ORNL is developing methods to reduce statistical bias in the 1987 nationwide truck surveys: the Truck Inventory and Use Survey and the Nationwide Truck Activity and Commodity Survey. The sampling plans of these surveys will be evaluated to better plan and implement the next surveys in 1992.

FHWA's Highway Traffic Forecasting System has been redesigned by ORNL to provide improved forecasts of trucking activity nationwide and of the impacts of this activity (in terms of pavement loadings) on the condition of the nation's highways. Related research in highway network design is looking at possible alternative designated routing options for trucks. Improved routing will allow more economical transporting of goods across country and will reduce the potential for considerable damage to our highway system's infrastructure. More effective highway network design and routing policies can also benefit DOE because they will provide better options for the shipment of spent nuclear fuel. ORNL is helping FHWA to examine future federal network design options, to ensure national network connectivity and to anticipate future traffic growth.

Innovative log-linear modeling of vehicle-miles-of-travel by vehicle type, roadway class, season, and state provides FHWA with a means of generating travel forecasts from large, sparse matrices containing large numbers of zero-valued cells. Research into the relationship between methods of forecasting vehicle-miles-of-travel and fuel use at the national level offers insights that are useful to both DOE and FHWA policy and planning staffs. ORNL is also increasingly involved in helping FHWA select and make the best use of sampling methods for the collection and analysis of truck freight transportation information.

To support these analytical efforts, and in cooperation with agencies within DOE and DOD, ORNL has been the leader in the development of an extensive national highway network data base that currently contains roadway lengths, traffic capacities, and other statistically and operationally useful planning characteristics for about 380,000 miles of highway. Workstation versions of this network data base are being developed for use in a variety of graphically enhanced highway research applications.

Other continuing work for FHWA has produced workstation-based simulation models and associated microcomputer graphics systems to replicate and depict complex traffic-stream management strategies for congested urban street layouts. In addition, ORNL will be increasingly

involved in providing FHWA technical support on research projects that study highway safety from the viewpoints of geometric design, highway systems operation, and hazardous materials transport. Application of expert-system methodologies to traffic-simulation problems is also emerging as a future research area.

In a cooperative venture with FEMA and FHWA, ORNL is developing real-time traffic monitoring and routing models. Real-time traffic analysis is a rapidly growing area of work, dealing with the increasingly important issue of the energy and environmental effects that vehicle traffic may have on our cities.

ORNL will also support FHWA's expanding research on intelligent vehicle and highway systems. This area of research holds promise for reducing congestion and highway accidents through advanced electronic traffic monitoring and control systems, together with intelligent vehicles and guideways.

In addition, the Federal Aviation Administration (FAA) is developing a modeling and analysis facility, the National Airsystem Management Facility, for the development of advanced systems for airport and airways management. ORNL is well suited to provide research support to this new facility, and to other operations research and simulation efforts in FAA, by virtue of its extensive R&D work for the Military Airlift Command.

Department of the Interior, Bureau of Mines

ORNL is developing some innovative resource-modeling techniques for the Bureau of Mines that will be used to study the relative competitiveness of the U.S. mineral industry, the impacts of acid rain legislation on the minerals industry, and the economic impacts of the development of advanced materials.

Department of Commerce

ORNL is providing technical assistance to the National Oceanic and Atmospheric Administration of the Department of Commerce. The CoastWatch Program has focused on the Eastern seaboard and especially on the Chesapeake Bay. Current work will provide land cover classification and change detection for two additional time periods based on more detailed satellite imagery for the entire Chesapeake Bay. Its purpose is to establish a base of knowledge and experience for the national CoastWatch effort and to provide wetlands data to the user communities including the Coastal Oceans Program and Chesapeake Bay Program. This effort will progress in tandem with workshops to develop protocols and to initiate the national CoastWatch effort.

ORNL is helping the Department of Commerce, Bureau of the Census, plan the year 2000 Census by assisting in managing changes in technology. Upcoming work in this area will focus on automating year 2000 Census field offices.

Central Intelligence Agency

Discussions are under way to explore ORNL support for the CIA in the area of intelligent systems, including image processing and understanding, and machine intelligence.

Other Federal Agencies

ORNL also provides technical support to a variety of other federal agencies, including the Consumer Product Safety Commission. We also anticipate collaborative work with the USDA, including the Agricultural Research Service, the U.S. Forest Service, and the USDA Research Laboratories at Beltsville, Maryland, and other sites throughout the country.

Some support to ORNL has been provided by the U.S. Department of State for work performed for the International Atomic Energy Agency and UNESCO, and we expect this support to continue. Collaborative research for the National Park Service, taking place at the Great Smoky Mountains National Park, is expected to continue.

Support has also been provided by the U.S. Department of Education, the U.S. Department of Justice, the U.S. Department of

Labor, and the Tennessee Valley Authority. ORNL provides support to the Bureau of Labor Statistics in AI systems to provide estimation of consumer prices index and survey decision.

Finally, new work is anticipated in support of the Office of National Drug Control Policy and its various support agencies.

Nonfederal Organizations

Electric Power Research Institute

The Electric Power Research Institue (EPRI) continues to fund research at ORNL in areas related to the generation and efficient use of environmentally acceptable electric energy. Major efforts in this area have been directed at the following issues:

- understanding the processes and mechanisms by which atmospheric deposition of energy-related pollutants affects the nutrient cycling and the sulfur and nitrogen dynamics of forest ecosystems,
- delimiting the relative importance and effects of wet and dry deposition of acidic substances in both forest and agricultural systems,
- developing a mechanistic and predictive forest-cycling model to address potential future impacts of atmospheric deposition,
- understanding the processes and improving predictions of the response of fish populations to environmental stress,
- developing methods for analyzing data to make and support decisions,
- critical reviews of power-related issues associated with global climate change, and
- theoretical aspects of uncertainty.

The Laboratory expects to continue these and other programs for EPRI during the course of the planning cycle. ORNL is completing work on acid-deposition effects on agricultural and forest systems. Work is continuing in the Compensation Mechanisms in Fish Population Program. In FY 1990 the program was expanded to include model R&D specific for hydroelectric projects impacts, such as instream flow requirements and water-quality alterations. An anticipated activity with EPRI is the evaluation of forest response to elevated CO_2 and global climate change. In addition, a new project on the role of vegetation in remediating waste sites has begun.

EPRI continues to fund research at ORNL in areas related to the efficient use of electric energy. An efficiency research project currently under way is a test of full-size ice-storage systems for cooling commercial buildings. Also under consideration is a project to develop diagnostic procedures for detecting toxic by-products of power circuit breaker gases and a proposal to develop CFC replacement fluids in commercial chiller units.

EPRI is currently co-funding development and demonstration at ORNL of intelligent control systems for nuclear power plants. This includes such topics as validation and verification guidelines for software used in digital nuclear plant control systems and development of portable software that runs on a variety of hardware platforms.

In addition, ORNL is researching a portable operating system for power-plant controllers. This project is proposed as an exploratory research project for EPRI involving technology acquisition that may have a significant economic impact on control system software development and implementation. The project goal is the development and demonstration of a portable, real-time operating system compatible with the UNIX operating system. The results will indicate methods to minimize or eliminate the difficulties and expenses that a utility may encounter in transferring software between processors, as will be the case for future replacement of the computer hardware.

ORNL also has an expanding technology-development program for EPRI in the area of

high-temperature structural design methods and fracture-assessment procedures for advanced reactor and other high-temperature power plant components. In these activities, ORNL serves as EPRI's R&D arm in collaborative studies between EPRI, the Central Research Institute for Electric Power Industry in Japan, and the Central Electricity Generating Board in the United Kingdom. Results of these joint studies help to fulfill identified needs in DOE's liquid-metal and modular gas-cooled reactor programs.

Associated with EPRI research is work being funded by the Babcock and Wilcox Owners Group to develop an improved control system for the currently operating reactors of the B&W design. The project objectives are to identify, document, and resolve problem areas in the current control system, to develop the optimum system configuration, to explore technological improvements in control design methods, and to provide features that meet the expanded scope of control for the new control system. ORNL's project will be a control algorithm that will be implemented by the B&W Owners Group on a new digital control hardware.

An additional anticipated activity with EPRI is R&D on thin film materials for photovoltaic and other energy applications.

American Petroleum Institute

The American Petroleum Institute (API) supports research at ORNL to evaluate the pharmacokinetics and pharmacodynamics of benzene in humans. The work is intended to provide a better estimate of the risk of developing leukemia following exposure to low doses of benzene.

ORNL is also providing support to API in the area of global climate change by developing inventories of greenhouse gas emissions associated with petroleum product combustion. The inventories will focus on energy consumption and fugitive gas losses through production, refining, and distribution.

Other Nonfederal Organizations

ORNL performs work for several other nonfederal agencies. For example, R&D sponsored by SEMATECH addresses critical national issues related to the processing of high-density semiconductor chips. This work has emphasized the development of advanced etch technology for submicron device applications. Future anticipated activities with SEMATECH include other aspects of semiconductor processing and materials development.

Private industry has joined with ORNL to identify and test materials and products that are economically feasible, durable, and free of CFCs for increasing energy conservation in residential and commercial buildings. Agencies include the National Roofing Contractors Association, the Polyisocyanurate Insulation Manufacturers Association, and the Society of Plastics Industry.

ORNL has entered into a cooperative research project with Attic Seal to test convective heat losses in some types of attic insulation and to measure the effect of convective retarders to restrict this energy loss in residential building.

Other organizations involved with ORNL include

- United Kingdom Atomic Energy Agency;
- Japan Atomic Energy Research Institute;
- Canadian Atomic Energy Commission;
- Federal Republic of Germany Umweltbundesamt;
- Korea Advanced Energy Research Institute;
- International Atomic Energy Agency;
- National Institute of Radiation Protection of Sweden;
- Harvard University;
- universities of Georgia and Maryland;
- states of California, Virginia, and Alaska;
- Metropolitan Edison/General Public Utility;
- Pacific Power and Light;
- EG&G Energy Measurements, Inc.;
- Florida Institute of Phosphate Research;
- Battelle Laboratories;
- General Electric;

- Soap and Detergent Association;
- National Geographic Society; and
- Center for Indoor Air Research.

R&D Contributions for WFO Managed by Other Oak Ridge Facilities

ORNL will continue to provide scientific and technical support to WFO programs that are managed by other Oak Ridge facilities; these include the Space and Defense Technology (SDT) Program, the International Technology Program, the Data Systems Research and Development Program (DSRD), and the Hazardous Waste Remedial Action Program (HAZWRAP). Generally ORNL will take part in the R&D aspects of these programs and not in the development and implementation phases of the work except in the technology transfer function.

Space and Defense Technology Program

The mission of the Space and Defense Technology (SDT) Program is the application of Energy Systems' special and unique research, development, and prototype fabrication capabilities for the purpose of solving problems germane to national defense and space exploration. In this effort, the SDT Program utilizes the diverse and multidisciplinary capabilities of the Oak Ridge sites. In addition, maintaining and expanding the current knowledge base for future DOE missions and transferring technology to other Federal agencies and the private sector are important aspects of the program.

ORNL currently provides approximately 60% of the total SDT Program support to DOD and NASA. The ORNL project areas include applications of materials technology, robotics, development of unique data acquisition and analysis systems, environmental effects, optics development and precision mirror manufacturing technology, and energy storage systems.

Data Systems Research and Development Program

It is the mission of DSRD Program, in direct support of the U.S. government, to design, develop, and apply state-of-the-art information technologies that provide modern solutions to problems affecting mission performance of DOE and other federal agencies. Through program management, research, development of unique systems, and design of prototypes for advanced information systems, advanced computer techniques are committed to the solution of important national problems. Technology transfer is included as an integral component of the DSRD program through effective and innovative hands-on applications. The overall DSRD program provides centralized direction for data systems development and related work, including research, applied research, program management, and selected applications.

ORNL provides support for the DSRD program and is assigned the DSRD work that requires the unique research capabilities of the Laboratory. Examples of DSRD research areas to which ORNL contributes include the following:

- expert systems and decision support;
- enhanced data acquisition;
- simulation and forecasting;
- advanced parallel architecture design;
- measurement sciences;
- advanced computing systems support;
- logistics systems development;
- statistical and numerical methods; and
- training simulators and their design.

Some of the DSRD projects to which ORNL contributes include a simulator sickness project and design of Navy financial systems using AI design and control programs.

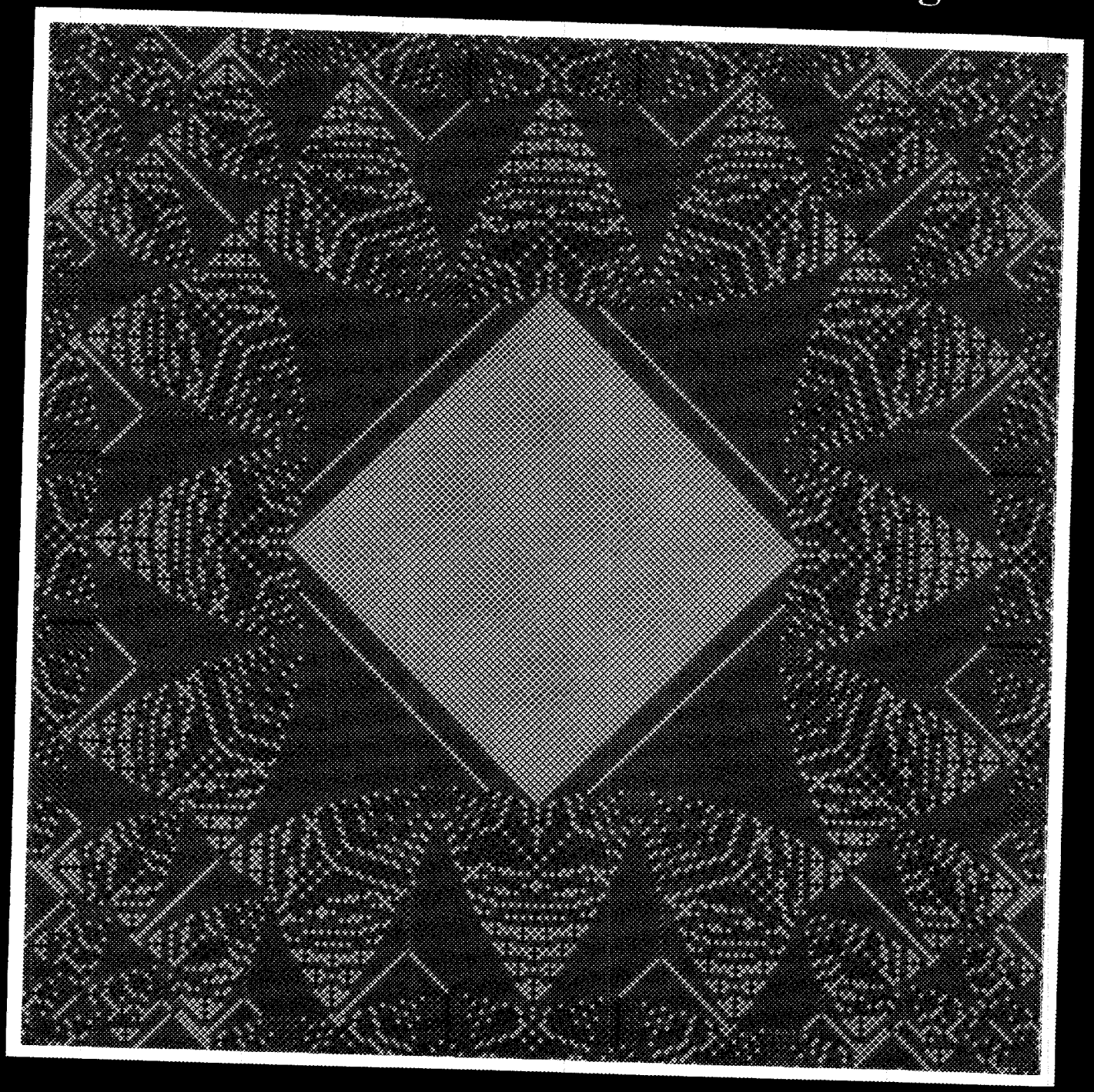
Hazardous Waste Remedial Action Program

The varied and complex waste issue at Oak Ridge, concerning low-level and other radioactive waste, hazardous waste, and mixed waste, has resulted in a large and growing R&D effort and level of expertise in waste treatment and characterization. Examples of technical efforts include solidification of waste forms, various destruction techniques for hazardous organic chemicals, exotic detection methods, in situ treatment technologies, and modeling capabilities. Experience in addressing these problems is in high demand by DOD and other federal agencies, and this work aids in developing technologies to be used by DOE. The work is likely to grow in importance in the next few years.

Energy Systems is currently doing hazardous waste work for other federal agencies in two major areas: technical support and technology development. Energy Systems provides technology support to the various EPA regions and for the EPA Hazardous Waste Engineering Research Laboratory by reviewing proposed technologies and collaborating on technical problems. The Air Force Engineering Services Center, the Navy Energy and Environmental Support Activity (NEESA), and the Army Toxic and Hazardous Materials Agency all use ORNL researchers. HAZWRAP is also active in site characterizations for various federal sponsors.

Technology development is currently provided to the Air Force Engineering Services Center, NEESA, and EPA. Projects include removal of volatile organics from soil and groundwater, separation of heavy metals from sand, fixation of hazardous waste in stable forms, development of water cleanup methods, and stabilization of heavy metals. This area is growing rapidly and will continue to expand over the next several years.

Education and Technology Transfer Programs



Education and Technology Transfer Programs

University and Science Education Programs

Overview of ORNL's University and Science Education Programs

The DOE University and Science Education Programs (USEP), Office of Energy Research, supports research participation and training for students and faculty at the Laboratory through both ORNL and the Oak Ridge Associated Universities (ORAU). Many more participants are supported by programmatic funds housed in the Laboratory's divisions and by other sources, such as colleges and universities, fellowships, and grants. Over 1000 university-based researchers are hosted annually at ORNL. Most of these appointments are sponsored by ORNL divisions through long-standing collaborative research projects. In addition to these collaborations with universities, ORNL has seen significant expansion of its precollege programs. In response to the increased interests in using national laboratory resources to help attain DOE and national education goals, ORNL established an Office of Science Education Programs and External Relations (SEPER) in February 1990.

ORNL plays an important role in the education and training of university students through a myriad of programs designed to provide research experience. During FY 1990, 17,000 guests at ORNL were affiliated with educational institutions, either as precollege students and teachers, undergraduate and graduate students, faculty, or postgraduate appointees. Most of the guests visit for short terms, but about 400 are devoted full time to ORNL divisions involved in research that may last from 1 to 2 years. This produces over 400 person-years of program assistance. The guests are hosted by the Laboratory through a variety of mechanisms:

- awarding research and development subcontracts;
- encouraging short-term research in the designated DOE User Facilities and other resources;
- supervising students and collaborating with faculty through research participation appointments;
- donating and loaning personnel and equipment resources;
- establishing close collaborations with specific universities and university consortia; and
- participating in short-term visits through the Ecological and Physical Sciences Study Center.

DOE and ORNL also benefit from university programs. Manpower projections performed for DOE indicate that the demand for well-qualified, trained scientists and engineers will continue to increase, particularly in the fields of health physics and computer science. At the same time, trends point to a decreasing number of science and engineering graduates, especially those who are U.S. citizens. To ensure a supply of personnel to perform energy-related research, DOE has a comprehensive program designed to improve the quality of science education and to increase the number of students electing to study science. ORNL plays an integral role in this program to enhance the research capabilities of educational institutions and to train students for careers in research.

Working with universities is a cost-effective way to achieve ORNL's programmatic goals. ORNL awards numerous R&D subcontracts to universities that sponsor research on campus in support of the Laboratory's missions. In addition, a number of programs are coordinated through the Office of University and Educational Programs whereby students and faculty participate in

research at the Laboratory. With this arrangement, the Laboratory benefits from having additional "staff" without the costs of hiring additional researchers.

In addition to being cost effective, university personnel make substantial contributions to ORNL's missions. Over the two decades that ORNL has hosted undergraduate students on academic-year science semester programs, students have made substantive contributions to ORNL projects that later were patented and/or received I•R 100 awards. Furthermore, working with university personnel supports the Laboratory's technology transfer objectives.

Over 35 different programs provide opportunities for students and faculty to participate in research at ORNL for appointment periods ranging from one-half day to several years. About one-half of the programs are administered through ORAU. Opportunities exist for summer or academic-year appointments. Comprehensive programs for graduate students include graduate internships, summer appointments, and thesis research.

Many university personnel receive training or perform experiments on ORNL's state-of-the-art resources while they are under research-participation appointments. DOE supports a variety of university programs at ORNL, both through USEP and programmatic funds.

Seventy-five co-op students were employed by ORNL in FY 1990; by contrast, about 324 students, 58 postgraduates, and 40 faculty received research-participation appointments through programs managed by the Office of University and Educational Programs. These numbers do not include more than 150 college and university personnel who received travel contracts for short-term research visits.

Programs are available through ORAU that help support travel costs for university faculty and graduate students under research travel contracts. Additional programs support travel costs for minority educational institution (MEI) researchers, such as Minority Institution Research Travel (MIRT) and Very Important Small Institution Travel Support. The supported visits may be to perform experiments at user facilities and resources or may be used for consultations with ORNL staff about common research interests.

University Consortia

ORNL has a close relationship with several university consortia. For example, ORNL has had a long-standing collaboration with ORAU on educational programs, which has been strengthened through the implementation of several new joint programs as well as joint university outreach activities. In FY 1986, ORNL began discussions with the Southeastern Universities Research Association (SURA), which is another consortium of major universities in the Southeast. In FY 1989, ORNL became a partner along with ORAU and SURA in a new initiative to establish at ORNL a Center for Study of Advanced Materials. This collaboration will provide a mechanism for faculty and students from SURA schools to work together as teams on research projects at ORNL. Dissertations will be presented on these projects for graduate students to earn either a master's or a doctorate. Papers will be issued through ORNL for the participants to receive their degrees. ORNL also continues to have a strong semester program with the Great Lakes Colleges Association/Associated Colleges of the Midwest (GLCA/ACM), now in its second decade.

Research and Development Subcontracts

ORNL awards about 100 R&D subcontracts to over 35 universities annually. These subcontracts generally sponsor research on campus but may also include provisions for student internships or faculty appointments to perform research at the Laboratory. About a third of these subcontract obligations are with The University of

Tennessee, Knoxville (UTK) (including the cost for the joint appointments under the Distinguished Scientist Program).

Research Collaborations

Many long-standing, close collaborations based on mutual research interests exist between ORNL and individual universities. About one-third of ORNL's annual R&D subcontract expenditures goes to support collaborative research at 20 prestigious colleges and universities such as the Massachusetts Institute of Technology, the University of Illinois, and the University of California at Berkeley. Most of these collaborations involve outstanding departments at these premier research institutions and include active exchanges of students and faculty.

ORNL is also engaged in a team R&D effort for the deployment of an advanced robotic system capable of performing tasks that are hazardous to humans or whose execution times can be reduced if performed by automated systems. The goal of this project is to develop a generation of advanced robotic systems capable of performing surveillance, maintenance, and repair tasks in nuclear facilities and other hazardous environments. This goal will be achieved through a collaboration among ORNL; the universities of Florida, Michigan, Tennessee, and Texas; and a number of industrial partners. The program is designed to take full advantage of existing resources at all participating institutions. ORNL participates in the research, coordinates the overall effort, and conducts coordinated experiments and integrated equipment tests to demonstrate the overall progress of the team.

ORNL has established a Center for Global Environmental Studies. The center will expand existing global environmental activities in the DOE-sponsored Carbon Dioxide Information Analysis and Research Program to include other trace gases important in the greenhouse effect, ozone depletion causes and effects, and the role of deforestation and reforestation in the climate issue. The center will draw heavily on contributions from universities, other DOE laboratories, and other research institutions.

ORNL plays a role in enhancing education and research facilities on campus. For example, as part of subcontract agreements, equipment necessary to carry out the research may be purchased. In the past, all equipment had to be returned unless it was too costly to transport. However, recent changes in DOE policy have allowed equipment purchased under subcontract for less than $5000 to remain the property of the school upon termination of the work.

ORNL also participates in the DOE Excess Research Laboratory Equipment program that allows colleges and universities to obtain excess equipment for the cost of transportation only. The equipment ranges from small detectors to sophisticated analytical instruments and may be new, used, or in need of repair.

Besides providing equipment resources, ORNL works with academic institutions to enhance their educational programs and research capabilities by donating staff expertise and resources. ORNL staff members frequently give seminars at universities throughout the nation, either via an ad hoc invitation from faculty or through formal programs such as the ORAU Traveling Lecture Program and the Industrial Research Institute Visiting Scientists Program. These visits, typically lasting a day, allow students and faculty to consult extensively with the scientist and give university personnel insights into some of the cutting-edge science performed at the Laboratory. About 75 to 100 of these visits are made annually.

Many ORNL staff members are affiliated with universities on an adjunct basis to teach classes and to collaborate with faculty on research projects. Some 20–30 adjunct professors from ORNL receive compensation under official appointments from UTK. Many others donate their teaching talents to other institutions, such as Knoxville College, Tennessee Technological University, and Roane State Community College.

ORNL staff also teach short courses as part of ORAU manpower training programs sponsored

by DOE. ORNL also provides other types of assistance to faculty, including critical review of proposals and manuscripts and organization of joint meetings and conferences.

Facilities and Equipment at ORNL

ORNL is the home of 13 designated DOE user facilities. These facilities offer unique opportunities for outside researchers to perform experiments on state-of-the-art equipment at minimal cost. Many of these facilities are supported by separate operational funds, and users need pay only their travel and housing costs.

In FY 1990, nearly 300 university researchers performed experiments for 5610 user days in ORNL's DOE user facilities. The largest percentage of the university-based users (31%) performed research at the Holifield Heavy Ion Research Facility (HHIRF). Other facilities heavily used by university researchers include the Oak Ridge National Environmental Research Park and the Surface Modification and Characterization Collaborative Research Center.

Other unique resources that may be available to university researchers include supercomputing capability (the new Intel iPSC/860 parallel supercomputer, a Cray X-MP, and two 64-node parallel processors), advanced electron microscopes, analytical equipment (including a new Fourier transform mass spectrometer), and other research tools. In addition, the Walker Branch Watershed, located on the Oak Ridge Reservation, is one of the best sites in the world for watershed research.

Precollege Programs

Much of ORNL's interest in precollege programs is in response to the federal government's renewed interest in science and mathematics education. Concern has been raised about the quantity and quality of science and mathematics training at both the college and precollege levels. Some problems manifested in the university relate to poor precollege preparation and declining enrollment, especially enrollment of U.S. citizens and of minorities. Within the last several years, DOE has also recognized that this problem may affect our nation's ability to compete in international research arenas in the future. Therefore, DOE has implemented several precollege programs designed for both students and teachers. ORNL has also responded to the calls for action with several new precollege activities, organized and managed by university and educational programs working closely with Public Relations staff.

ORNL hosts high school teachers during the summer and high school students year-round. In addition to research participation, other events are organized for summer guests to the Laboratory, including a seminar series that focuses on major Laboratory programs and a series of tours that illustrate the variety of research at ORNL.

For many years, several programs have existed to avail the Laboratory to high school students and teachers. In the summer of 1985, 14 high school teachers participated in the pilot Summer Field Experience program that allowed them to assist ORNL researchers for 6 weeks.

Two new summer research programs, the TRA (Teacher Research Associates) and the STAR (Summer Teachers As Resources), were established during FY 1989. The TRA program, sponsored and funded by the Office of Energy Research, involves a local as well as a national component. On a national level, states nominate their outstanding mathematics and science teachers for participation in the TRA program. Locally, outstanding teachers in the area are selected for participation, providing a group of participating teachers representing a cross section of the nation. STAR is a pilot program whose goal is to assist the Oak Ridge schools in recruiting and retaining quality teachers, with an emphasis on the inclusion of minorities, by providing the opportunity for summer employment. STAR differs from other teacher programs in that participants are drawn from all academic levels and disciplines.

In FY 1990, 104 teachers participated in research activities through these various programs at ORNL. These participants included 46 elementary-level (K–8) teachers and principals from 10 East Tennessee–area counties, part of the first National Teacher Enhancement Program workshop. Sponsored by the National Science Foundation, the program is coordinated by ORNL with four other participating DOE laboratories. The workshop centered on material sciences research. More than 25 area teachers and ORNL research staff were used as resource persons.

For the third year, about 60 high school students (from the United States and 7 other countries) were hosted by ORNL in one of the DOE National High School Honors Workshops (Fig. 49). Once again the focus was on environmental sciences. During their stay at the Laboratory, these students were involved in environmental studies dealing with the effects of contaminants on the environment. The Special Honors Study program, first implemented in FY 1986, allows exceptional high school students to conduct a study project in an area in which they have a special interest. These projects are conducted at the Laboratory under the supervision of an ORNL staff member. Ten students participated in the program in FY 1990; ORNL has had a total of 30 participants since the inception of this program.

Initiatives are also being developed and expanded to involve students traditionally

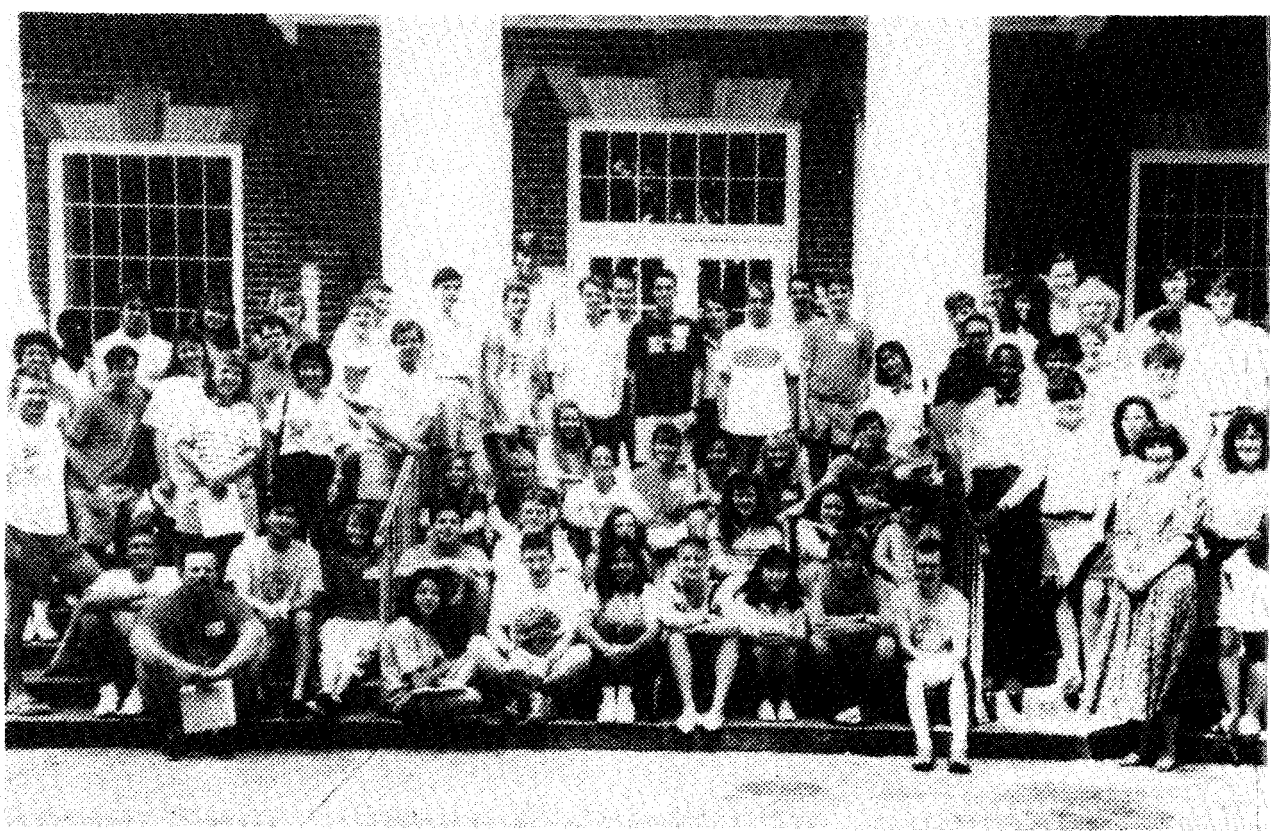


Fig. 49. Sixty outstanding junior and senior science students from across the United States and seven foreign countries participated in the third DOE High School Honors Workshop hosted for two weeks in July by ORNL's Environmental Sciences Division. The U.S. students, nominated by the governors of the fifty states, District of Columbia, and Puerto Rico, were joined for the two-week session by young people from Canada, France, Italy, Japan, Mexico, and the United Kingdom.

underrepresented in precollege programs in an effort to increase the pool of citizens who elect to pursue careers in science and engineering. One example is the Summer Educational Experience for the Disadvantaged (SEED), a program to encourage economically disadvantaged high school students to consider careers in science and mathematics. This program was initiated in the summer of FY 1988 with a student being placed in the Chemical Technology Division. In FY 1990, SEED was expanded to include 17 students. Participants are actively involved in research as well as activities leading to career development and expanded scientific knowledge.

As part of this increased focus on precollege activities, ORNL continues to expand the Ecological and Physical Sciences Center (the Study Center), which is one of the most visible and successful precollege programs. The Study Center was formerly the Ecological Study Center (ESC) of the Oak Ridge National Environmental Research Park. Developed by a team of educators, ESC began in 1983 with four study units functioning during the spring and winter. The Study Center now includes 32 study modules that provide students with the opportunity for hands-on learning in both the life sciences and physical sciences. The units are offered generally as half-day field activities and are tailored for the academic level of elementary, junior high, or senior high school students. The Study Center now operates year-round, including Summer Science Saturdays for adult community members and children. During FY 1990 over 16,000 participants were hosted. Demand for the program continues to be strong; many more requests are received than can be accommodated. Several of the study units have been adapted for use by students with disabilities.

Partnerships with Oak Ridge, Knoxville's Vine Middle School, Roane County, and Chattanooga City schools have been developed, linking the science departments of the schools with the resources of the Laboratory. The Laboratory possesses unique skills and a knowledge base that can assist the schools in enhancing the scientific educational experiences of both students and teachers. These partnerships will serve as models of how communities and laboratories can benefit from such partnerships.

Undergraduate Programs

A prime emphasis in ORNL educational efforts lies with programs geared to mainly upper-class college and university students who major in science, mathematics, computer science, or engineering. The primary goal of such programs is to encourage these students to pursue graduate studies and careers in these disciplines.

Participants in semester-length programs are increasing in number. Admission to the GLCA/ACM Fall Semester, a long-standing program at ORNL, continues to be sought by students from the colleges of that consortium. A 10-year survey of these participants indicated a pronounced effect of the Oak Ridge experience on pursuit of graduate studies and career choices in the technical fields.

The U.S. Department of Energy-Office of Energy Research (DOE-ER) funded Science and Engineering Research Semester (SERS) Program is now in its fourth year at ORNL and five other national laboratories. At ORNL, this program has been modeled after the highly successful GLCA/ACM Program. The SERS Program draws from colleges and universities across the United States, and the class size for this program has almost doubled at ORNL since its inception. The longer term of appointment and established funding adds to the value of these semester programs for ORNL laboratories and scientific staff.

Other programs that can provide extended-term appointments for undergraduates include the ORAU Professional Internship Program in which appointees can do research at the Laboratory for up to 12 months consecutively for a total maximum term of 18 months. The Technology Internship Program, developed to enhance training for technical students in two-year colleges, also is structured to allow longer and more flexible terms

of appointment. ORNL has already hired several permanent technical employees from this group of participants.

Summer educational programs make it possible for students to work in ORNL research laboratories for approximately 10 weeks. These terms are generally open for most students and are a popular avenue for many who wish to experience research at a national laboratory. The Service Academies Research Associates Program (SARA) is another relatively new program designed to provide a summer research opportunity for rising seniors from one of the U.S. military academies.

Graduate Programs

Prethesis graduate students in master's and doctoral programs, master's degree and Ph.D. candidates performing thesis or dissertation research, and postdoctoral participants are appointed to ORNL through various graduate education programs. The goal of these programs is to enhance the educational experiences of these students by providing opportunities to work in laboratory situations with advanced equipment not readily available on their home campuses. A major consideration in the selection of these students is the compatibility of their background and interests with research projects in ORNL divisions. In addition, students in the postdoctoral programs and the Laboratory Graduate Participation Program undergo a highly selective procedure by the ORNL Graduate Fellowship Selection Panel or the Alexander Hollaender Distinguished Graduate Fellowship Selection Panel. Graduate-degree candidates, performing research for a thesis or dissertation, work under the supervision of a graduate committee composed of representatives from their schools and ORNL. Postdoctoral appointments provide valuable research contributions to ORNL staff and divisions. Work for these appointments is planned to support specific programmatic needs at the Laboratory.

Students who have not yet completed the required course work can participate in the ORAU Professional Internship Program for graduate students and the ORAU Graduate Student Research Participation Program. These programs are structured to provide prethesis research experiences for students aspiring to degree candidacy. Many of these participants are selected later for the higher level programs.

The University of Tennessee, Knoxville

UTK enjoys especially close ties to the Laboratory. Many UTK faculty members have served as consultants and research participants at ORNL. ORNL staff have served on UTK advisory committees, and UTK staff have played a similar advisory role at ORNL. Many ORNL staff have taken advantage of the UTK Resident Graduate Program in Oak Ridge, which offers evening courses to those pursuing advanced degrees in a variety of scientific and engineering disciplines.

Science Alliance

The Science Alliance, funded by the State of Tennessee, ORNL, and DOE as part of the Comprehensive Education Reform Act, is another example of collaboration between ORNL and UTK.

The purpose of the Science Alliance is to encourage joint research collaborations between ORNL and UTK, thus fostering a unique environment for research training. Many different activities fall under the program's umbrella, but the one most visible is the Distinguished Scientist Program, whose purpose is to strengthen R&D in the region by attracting scientists and engineers of high national and international stature. The selected scientists hold a tenured position as full professors at UTK and appointments as senior research scientists at the Laboratory. ORNL and

UTK share the costs of these appointments equally. Several have already made substantial impacts on both UTK and ORNL through the number of personnel and contract awards that they have accumulated since the start of their appointments. To date a total of 11 Distinguished Scientists have appointments at ORNL and UTK.

Other activities sponsored by the Science Alliance include a summer research program at ORNL for undergraduates and the development of joint graduate programs. These joint programs include a new Master of Science program in biotechnology and a graduate program in measurement and control engineering.

The UTK Graduate Programs at ORNL

Perhaps the least known, yet strongest, ORNL-UTK joint programs are the two UTK graduate schools located at ORNL: the Oak Ridge Graduate School of Biomedical Sciences (ORGSBS) and the Graduate Program in Ecology. Both graduate programs at ORNL provide a home for several UTK faculty.

Housed in the Biology Division at ORNL, ORGSBS (established in 1965) offers full-time graduate study for M.S. and Ph.D. degrees and for postdoctoral training. Student support is provided by UTK through research assistantships and federal grants. Most of the school's teaching and research training is provided by Biology Division staff. The current enrollment is around 40 graduate students and postdoctorate appointees.

The second UTK graduate program at ORNL is the Graduate Program in Ecology (established in 1969) within the Environmental Sciences Division (ESD). Similar to ORGSBS, the ecology program offers full-time graduate study for M.S., Ph.D., and postdoctoral students. The students are largely supported by ESD programmatic funding. About 20% of the research training is provided by ESD staff, who also teach courses under adjunct appointments. Enrollment is typically about 15 graduate and postgraduate students.

Minority Educational Institutions

ORNL continued to expand program interactions with MEIs during FY 1990. The main thrust of the program is to develop opportunities through internal and external interactions. Internally, the program emphasizes communication of Energy Systems' MEI program objectives; externally, attempts are made to encourage MEI participation in research through workshops, established contact networks, mutual visitations, and professional assistance. Program activities and initiatives are under way with a number of institutions toward the overall goal of increasing the number of scientists and engineers to help contribute to the manpower needs projected for the future.

The memorandum of understanding (MOU) with the University of Puerto Rico (UPR), established in FY 1988, continues to be a highlight toward increased interactions with Hispanic institutions. During FY 1990, the MOU provided a mechanism to support two faculty and four students to conduct research in various ORNL divisions. Subcontract activity through ORNL divisions also provides another mechanism for collaboration.

As part of the historic Memorandum of Understanding and Intent, forming support for the DOE-ER Science and Technology Alliance, ORNL continued collaborations with the Alliance Educational Institutions, which include North Carolina A&T State University (NCA&TSU), New Mexico Highlands University, and the Ana G. Méndez Educational Foundation (AGMEF). For the second year, ORNL provided funding to NCA&TSU in the amount of $372,000 for program administration, student and faculty development, curricula development, and special precollege programs to help encourage the pipeline of science and engineering students.

Fiscal year 1990 saw extensive interaction between ORNL and alliance faculty and students from NCA&TSU and AGMEF. Also, for the second year, ORNL has provided support to New Mexico Highlands University in the establishment

of a library to support their efforts toward Accrediting Board for Engineering and Technology accreditation for their School of Engineering Technology. ORNL has also supported precollege students and faculty through a special precollege initiative developed last year. In addition to existing subcontracts in materials science with NCA&TSU, which have been ongoing for several years and total more than $1.5 million, this period saw an expansion of these R&D collaborative efforts between ORNL and NCA&TSU into a new area: mathematical modeling (symbolic modeling of mechanical manipulators). A subcontract was let for $20,000 to the school's Mechanical Engineering Department. Energy Systems' Information Services Division also supported a subcontract with the NCA&TSU Mass Communications Department. The purpose of the subcontract is for ORNL to develop an internship program with a minority institution that will produce a cadre of trained professional technical information specialists for ORNL. The initial cost of the subcontract is $25,000. Eight students and one faculty member from NCA&TSU participated in summer internship experiences.

Seven outstanding Puerto Rican high school students and two supervising teachers selected by AGMEF were brought to Oak Ridge during the summer of 1990 for 10-week research appointments at ORNL. Each carried out an independent research project and prepared a summary research report on the experience, which was reviewed and approved by the staff mentor. The students also took part in a weekly seminar with 10 other students appointed from schools in the East Tennessee area. At these sessions, students heard informal talks on various ORNL research programs (e.g., programs in fusion energy, genetic engineering, neutron activation analysis, and robotics) and shared the progress of their individual projects.

This first-of-a-kind effort was unique in that it provided summer-long assignments (2-1/2 months) for a group of young students (high school juniors and seniors) who were a long way from home (geographically and culturally). These students and teachers, selected by AGMEF for this experience, proved not only to be highly capable and mature in approaching and carrying out their research assignments but also very positive and disciplined in adapting to their new laboratory work and living environments.

In addition to this very important pilot program, support was provided for Dr. Doris Garcia of the Metropolitan University (one of the Méndez Foundation schools) to conduct research on the water relations of hybrid poplar cultivars. This was Dr. Garcia's third summer research appointment at ORNL.

ORNL and Energy Systems have MOUs with three other MEIs: Southern University, Clark Atlanta University, and Tuskegee University. In addition to faculty and student appointments during the summer of FY 1990, subcontracts totaling over $230,000 were also committed to these institutions to conduct mission-related research.

New Initiatives

There are several new activities that support initiatives mentioned in the DOE Math/Science Education Action Conference as well as other initiatives that support ORNL's expanded education mission.

- The Science and Mathematics Action for Revitalized Teachers program (SMART) is designed to increase the effectiveness of K–12 science and mathematics teaching through a multiyear effort with science and math teachers at all levels within two school districts—Chattanooga and Roane County. Working together in a partnership that involves local businesses, industry, and federal laboratories, a program will be developed to involve the teachers and administrators in individual and group summer and academic year experiences. As a result of these activities, teachers will be empowered to positively impact science and mathematics education in their schools.

- Activities under the DOE MOU with the Appalachian Regional Commission will be expanded during FY 1991 (Fig. 50). A pilot program was initiated during FY 1990 involving 17 middle and high school students and 3 teachers from school systems in Southwest Virginia. These "hands-on" learning experiences were based on the curriculum from the ORNL Ecological and Physical Sciences Study Center.
- ORNL will work with UTK in the establishment of an Academy for Teachers of Math and Science. This regional effort will be supported by the State of Tennessee, Martin Marietta Corporation, and DOE and will focus on science and mathematics teacher enhancement.

Another program, the National Science Foundation (NSF) National Teacher Enhancement Program, will begin its second year of support in FY 1991. The program offers a 3-week workshop to area K–6 teachers of mathematics and science. NSF provided a $2 million grant to five participating DOE laboratories (Argonne, Fermi, ORNL, Pacific Northwest, and Lawrence Livermore national laboratories) and ORAU to conduct regional workshops for area teachers. At the end of the period of performance (1990–1992), over 400 teachers will have participated in these enhancement activities. ORNL is serving as the lead laboratory in these efforts.

- The ORNL Partnerships at the Laboratory in

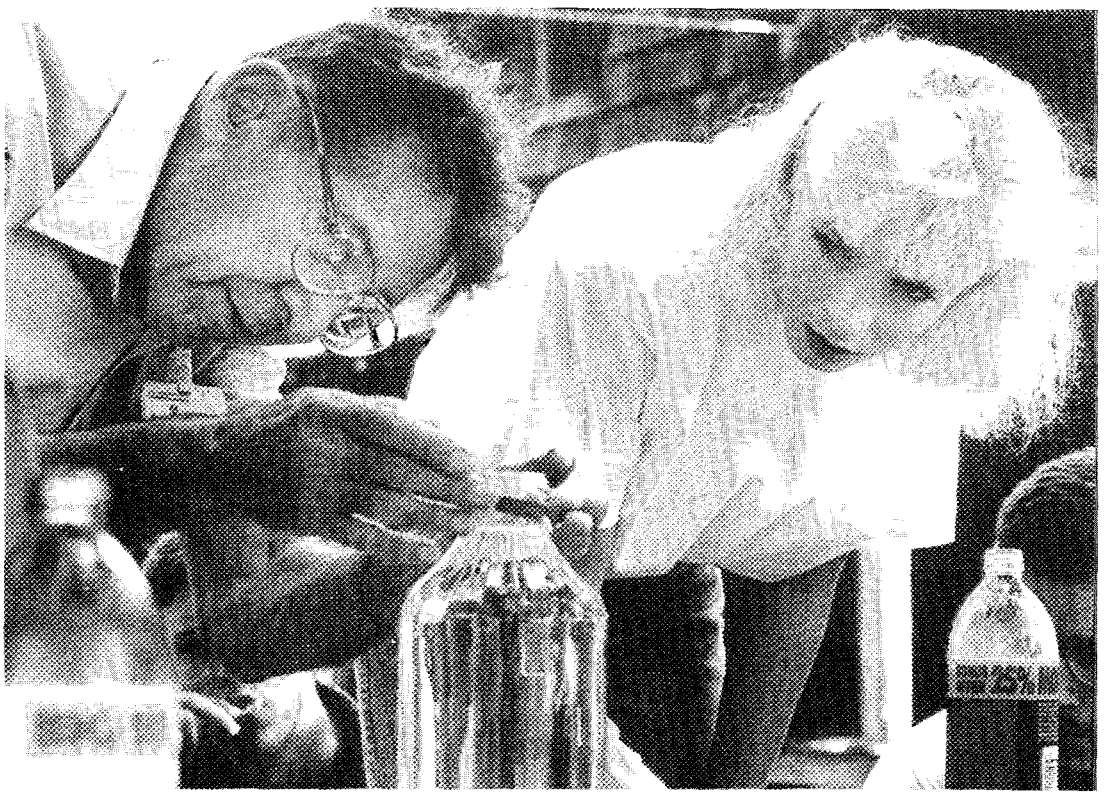


Fig. 50. Under a new DOE Memorandum of Understanding with the Appalachian Regional Commission, ORNL conducted its first residential Summer Math/Science Experience for 18 middle- and high-school students and their teachers from Smyth and Tazewell counties in Southwest Virginia. The two-week program emphasized "hands on" learning experiences in both the physical and life sciences. Staff of ORNL's Ecological and Physical Sciences Study Center conducted the pilot program.

Science is expanding its "adopt-a-school" program to include two local school systems in response to another of Secretary Watkins' initiatives, involving DOE laboratories in partnerships with "at-risk" schools. The two schools that will participate are Vine Middle School in Knoxville and Roane County High School. Each school represents "at-risk" populations of students, with a majority minority student body at Vine Middle School and a rural student body at Roane County High School.

- ORNL will begin a new precollege program this fall that will be known as the Saturday Academy of Computing and Mathematics (SACAM). SACAM is designed for selected seniors (or exceptional juniors) in East Tennessee area high schools who would be challenged by the opportunity to explore the applications of pure mathematics or computer science in solving scientific programs.
- MOUs with UPR and the Science and Technology Alliance will result in collaborations with the represented institutions through increased student and faculty research participation as well as through support of faculty and ORNL staff visitations. Precollege programs and joint research projects will be included in the collaborative efforts leading from the MOUs. Other precollege areas to be further developed concern programs that address specific manpower needs for DOE programs and missions.
- Programs will also be developed that involve efforts to provide activities for females and underrepresented minorities, to enhance mathematics education, to strengthen precollege education in the physical sciences, and to provide academic-year activities to revitalize teachers and students.
- ORNL, along with ORAU, will begin investigation into planning for sponsorship of regional high school science bowls. A similar collaboration would involve the sponsorship of a Careers in Science and Technology Workshop for regional minority students; this could encourage the pursuit of careers in science and technology and communicate various opportunities and mechanisms to do so.
- ORNL will continue to increase interactions with premier academic institutions. Toward this goal ORNL has established MOUs with Duke University and the University of California, Santa Barbara. Discussions are in progress with Cornell University concerning the possibility of establishing a MOU for collaborative work. ORNL is expanding its interactions with the service academies through the SARA program, thus increasing numbers of students from the Naval Academy, West Point, and the Air Force Academy. Faculty from service academies will also be encouraged to participate.
- A program of Graduate Student Research in Neutron Scattering has been proposed to DOE by ORAU. The program will ensure the availability of appropriately trained scientists to support neutron scattering research at DOE laboratories, and it is vital to the success of the Advanced Neutron Source to be built at ORNL. Neutron scattering education at academic institutions is limited, while several DOE laboratories currently conduct such research, including Ames, Argonne, Brookhaven, Los Alamos, and Oak Ridge. ORAU will recruit graduate students from universities to do thesis research at these facilities. Beginning in FY 1991, five graduate students will be appointed to the program each year. The program will reach steady state in FY 1994 when a total of 15 students will be supported by the program from a projected budget of $504,000.

The number of university research participants is expected to increase with the continuation of the Oak Ridge Science and Engineering Research Semesters. When fully operational, the program could support several hundred students annually for research participation and training, mostly during the academic year. A goal for the program is to house the students and faculty in a multipurpose building to be constructed in central Oak Ridge.

Summary

The university and educational programs will continue to grow significantly in the future. It is important that a facility be developed that meets the needs of our growing precollege and university programs. ORNL will continue to involve new groups in our activities, implement new programs to meet needs, and otherwise enhance our education and training activities. The catalog of programs currently offered by ORNL is considerable and impressive (Table 43), but opportunities for new initiatives still exist.

Table 43. Programs at ORNL for precollege and university participants (FY 1990)

Precollege	
Special honors study	8
Honors workshop	57
Ecological and Physical Sciences Study Center	16,000
University of Puerto Rico	16
Summer Educational Experience for the Disadvantaged (Project SEED)	10
Hispanic SEED (science and technology)	7
Appalachian Regional Commission	16
Total	16,114
Precollege teachers	
NSF workshop	46
DOE honors	10
Appalachian Regional Commission	3
DOE teacher associates	12
STAR	4
SMART	4
STRIVE	20
Science and Technology Alliance	2
University of Puerto Rico	3
Total	104
Undergraduate	
GLCA/ACM science semester	25
Health physics internship	0
Summer forestry	2
Special summer program	8

Table 43. (continued)

Summer research internship	42
Technology internship program	15
HBCU nuclear energy training program	11
Science and engineering research semester	57
Student research participation	54
Total	214
Graduate	
SARA	14
Professional internship program	25
Laboratory graduate participation	11
Graduate student research participation	4
Nuclear engineering research participation program	13
Total	67
Postgraduate	
Postgraduate research appointment	20
Office of Health and Environmental Research postgraduate appointment	1
Hollaender postdoctoral program	4
Postgraduate research training program	25
Fusion energy postdoctoral program	1
Total	51
Faculty	
Faculty research participation	34
MIRT	5
Research travel contracts	152
STRIVE	11
Office of Health and Environmental Research HBCU faculty	3
Nuclear Regulatory Commission HBCU faculty program	3
Tennessee Visiting Scientist program	15
Teacher research associates	13
STAR	4
Total	240

The ORNL SEPER Office will continue to grow and to act as a model for other federal laboratories and corporate entities in their efforts to enhance the education of the nation's youth. ORNL has demonstrated a commitment to increase the involvement of university personnel in its R&D activities. It is imperative to supply well-trained, qualified technical personnel for the

future. The Laboratory is assisting DOE in achieving this goal in two ways: (1) by providing opportunities for students of all ages to receive training and to perform research and (2) by encouraging students to attend graduate school in energy-related disciplines. The university interactions are also important in transferring science and technology through sponsoring faculty research participation and visits at ORNL and through ORNL staff visits and lectures on campus. Collaborative research programs with university personnel will continue to be a cost-effective method to receive quality assistance in fulfillment of the Laboratory's missions.

Guest Research and User Facility Programs

During 1989 the Office of Guest and User Interactions (OGUI) was established within the ORNL Central Management organization to enhance the level of service and improve the environment for Laboratory guests, to encourage cooperative R&D, and to facilitate access to user facilities by external scientists and organizations. OGUI includes the Foreign National/Guest Services Office and a contracts group. A member of the Office of General Counsel provides legal assistance as needed to support the OGUI program. OGUI works with DOE-Oak Ridge Operations, ORNL staff, and external researchers to develop and implement streamlined procedures and services related to the performance of research at ORNL by guest scientists and engineers.

User Facilities

ORNL has 13 user facilities designed to serve both the technical community and DOE missions by making these highly sophisticated facilities available for use by outside organizations. Since the user program was started approximately 10 years ago, these facilities have become an increasingly important factor in attracting scientists from industries and universities to the Laboratory (Fig. 51). In 1989, 390 academic and industrial guest researchers, 297 government laboratory researchers, and 51 foreign scientists conducted experiments at ORNL user facilities (Table 44 and Figs. 52 and 53).

Traditionally, more than one-half of these visiting scientists represent universities. In 1989, 43% of the total users were university scientists. Since the establishment of the High Temperature Materials Laboratory (HTML) user facility in 1987, the number of industrial users has been growing. In the ORNL user program in 1989, 66 industrial researchers representing 39 companies participated. In June 1990, the High Flux Isotope Reactor (HFIR) was restarted and began to operate at full power for the first time in more than 3 years. Two user facilities, the Small-Angle Scattering Research Center and the Neutron Scattering Facility (Fig. 54), which were directly affected by the 1986 shutdown, are again attracting users.

Guest Research

Users constitute only a part of the large number of guest researchers who work with Laboratory scientific staff for periods ranging from 2 weeks to 2 years. These interactions broaden the Laboratory's base of expertise and support its mission of scientific cooperation and technology transfer. In 1989, the Laboratory population was augmented by 2344 guest research assignments (Tables 45 and 46). Of this number, 570 were foreign nationals representing more than 50 countries. In the last 5 years, the number of guest assignments at the Laboratory has more than doubled.

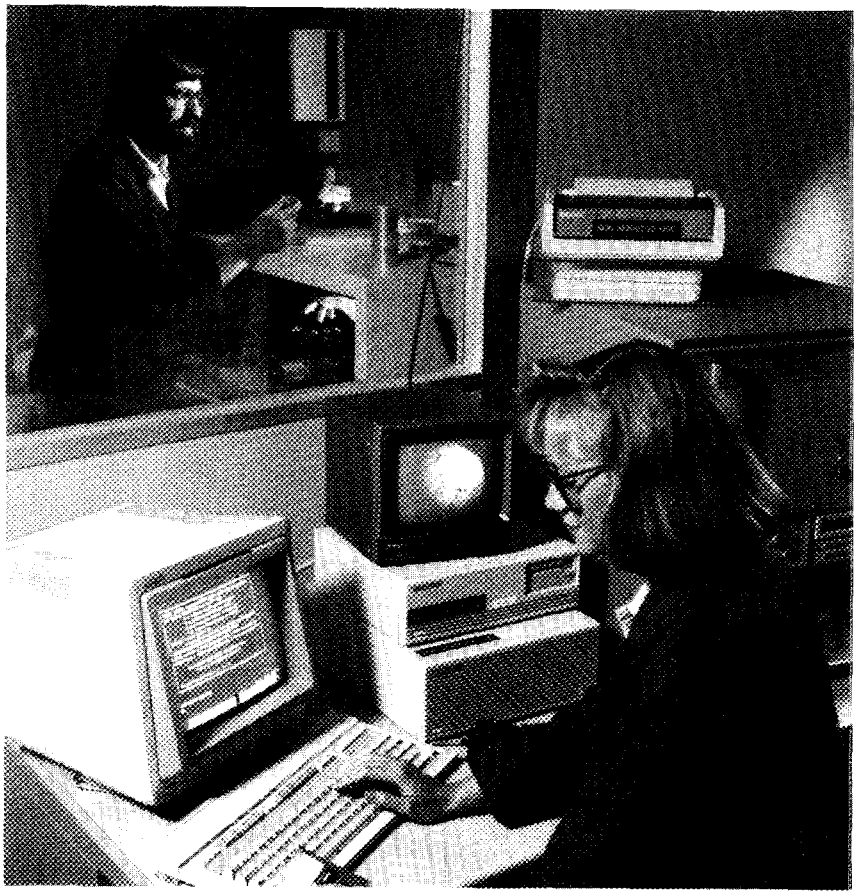


Fig. 51. An industrial user from Norton-TRW, Northboro, Massachusetts, loads a sample into the nanoindenter in the HTML. In the foreground, user staff technician, Becky Freeny, manipulates indents with the computer.

The Future

With more emphasis on cooperative research, the guest research population at the Laboratory is expected to continue to grow. New user facilities will expand the user program and will attract additional participants. Other programs, such as the Advanced Neutron Source, the ORNL Detector Center, the proposed hosting of International Thermonuclear Experimental Reactor engineering activities, and the Optics MODIL, are expected to attract increasing numbers of guest scientists to ORNL. OGUI will continue to enhance services that make the Laboratory more accessible and promote a friendly environment for guests.

Technology Transfer

In a letter to the Directors of the DOE national laboratories, Admiral James D. Watkins said the following:

"Technology transfer is a mission for the national laboratories and the DOE. I would like

Table 44. Experimenters at designated user research facilities in FY 1989

	U.S. Gov't Lab.			University			Industry			Foreign			Total		
	Exp.	Org.	% Use	Exp.	Org.	% Use	Exp.	Org.	% Use	Exp.	Org.	% Use	Exp.	Org.	User days
Holifield Heavy Ion Research Facility (HHIRF)	41	4	40.5	124	32	49.7	0	0	0	25	15	9.8	190	51	2,106
National Environmental Research Park	37	4	42.7	41	15	37.9	9	4	11.1	3	3	0.1	100[a]	30[a]	3,468[a]
High Temperature Materials Laboratory (HTML)	88	4	61.2	37	18	10.5	33	20	28.3	0	0		158	42	2,363
Surface Modification and Characterization Laboratory (SMAC)	50	6	77.7	32	14	16.0	9	7	1.5	10	5	4.8	101	32	1,729
Shared Research Equipment (ShaRE)	31	1	84.0	26	11	14.8	1	1	0.3	1	1	0.9	59	14	944
National Center for Small-Angle Scattering Research (NCSASR)[b]	16	4	42.3	38	21	40.5	10	5	6.0	3	2	11.2	67	32	787
EN Tandem Van de Graaff	10	2	40.7	18	3	51.3	0	0		4	2	8.0	32	7	1,753
Oak Ridge Electron Linear Accelerator (ORELA)	21	4	88.1	1	1	1.6	1	1	0.4	3	2	9.9	26	8	1,362
Bioprocessing Research Facility	3	1	14.8	6	5	75.4	3	1	7.4	1	1	2.4	13	8	122
Roof Research Facility	0	0		1	1	39.6	0	0		1	1	60.4	2	2	159
Neutron Scattering Facility[b] (located at HFIR)	0	0		0	0		0	0		0	0		0	0	0
Health Physics Research Reactor (HPRR)[c]	0	0		0	0		0	0		0	0		0	0	0
Low Temperature Neutron Irradiation Facility (LTNIF)[c] (located at Bulk Shielding Reactor)	0	0		0	0		0	0		0	0		0	0	0
Totals (experimenters and % use)	297		56[d]	324		29.8	66		8.4	51		4.5	748[a]		14,793

[a]The totals for the National Environmental Research Park include 10 users from 6 organizations (8.2% of the park's use and 1.3% of the total research facilities' use) that are not covered by the four categories listed in the table.

[b]Facility affected by DOE reactor shutdown of HFIR from November 1986 until April 1989 and subsequent DOE suspension of operations from May 1989 until January 1990.

[c]Facility affected by the March 1987 DOE order to shut down all ORNL research reactors.

[d]Includes 254 ORNL users (49.7% of use).

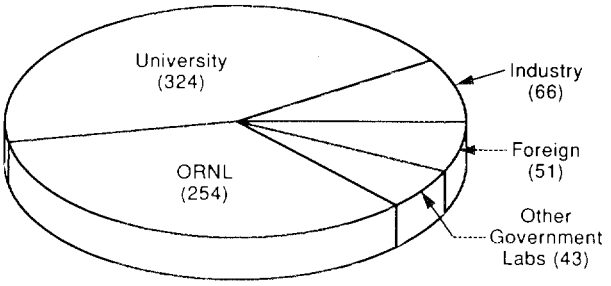


Fig. 52. Participants at ORNL user facilities (FY 1989).

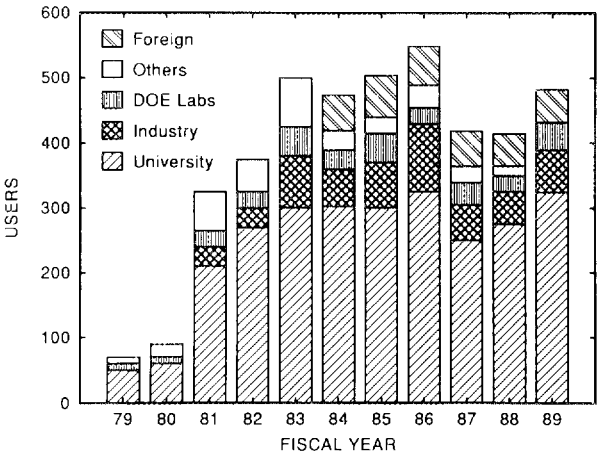


Fig. 53. Number of outside users of ORNL facilities.

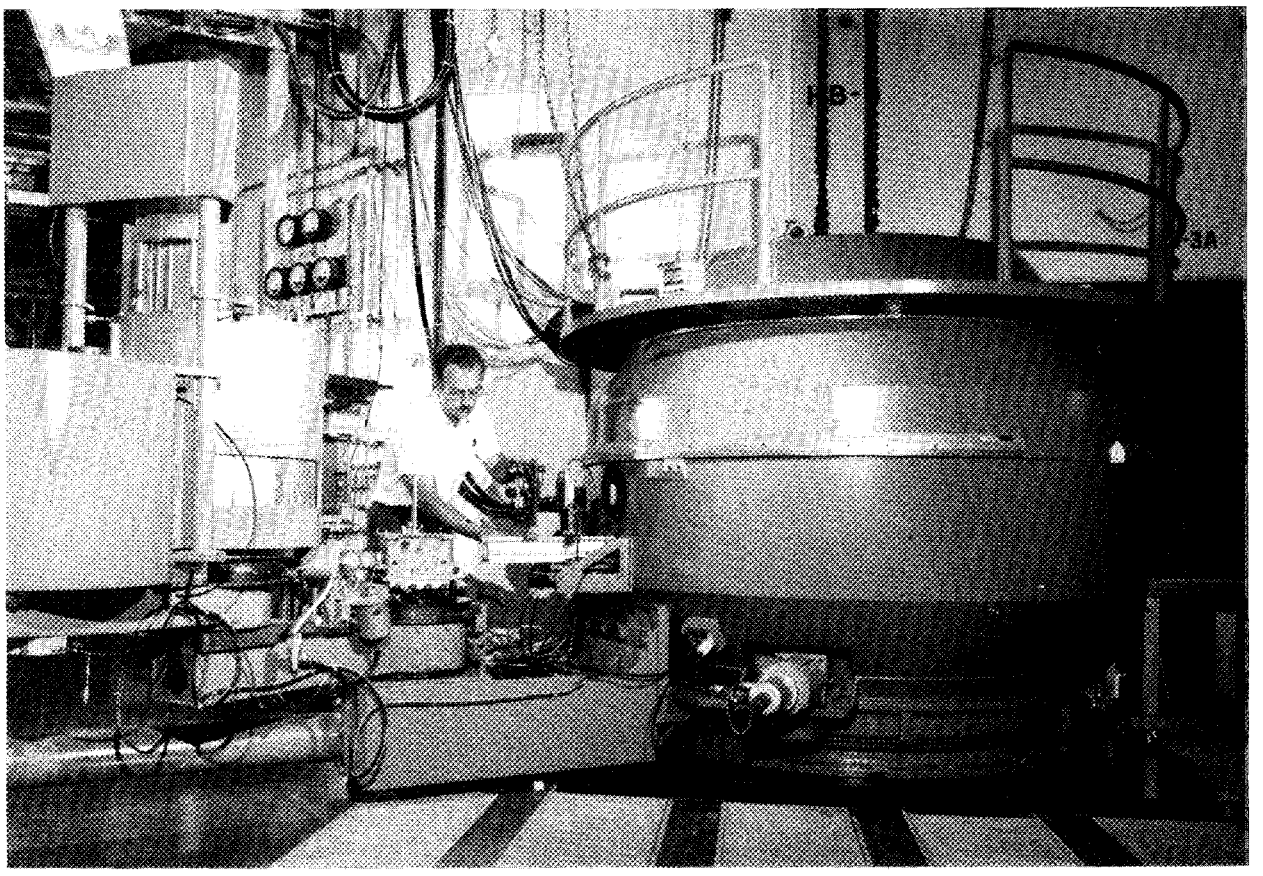


Fig. 54. Bob Nicklow at the HB-3 triple-axis spectrometer. This instrument, used to measure excitations in single-crystal samples, is available for industry and university users at the Neutron Scattering Facility located at the HFIR.

Table 45. Number of guest assignments at ORNL

Research sector	Fiscal year					
	1984	1985	1986	1987	1988	1989
University	628	920	967	1378	1428	1395
Industry	260[a]	344[a]	398[a]	617	689	736
Federal agencies				39	40	52
Foreign institutions	97	83	77	62	59	48
Other	49	59	191	77	88	113
Total	1034	1406	1633	2173	2304	2344

[a]Includes federal agencies.

Table 46. Percentage of total guest assignments at ORNL

Research sector	Fiscal year					
	1984	1985	1986	1987	1988	1989
University	60.7	65.4	59.2	63.3	62.0	59.5
Industry	25.1[a]	24.5[a]	24.4[a]	28.4	29.9	31.4
Federal agencies					1.8	2.2
Foreign institutions	9.4	5.9	4.7	2.8	2.6	2.1
Other	4.7	4.2	11.7	3.5	3.8	4.8
Total	100	100	100	100	100	100

[a]Includes federal agencies.

your institutional plans to focus on making technology transfer an integral part of your laboratory's culture. It is not enough to communicate to the individual researcher the importance of increasing the rate of transfer of new laboratory technologies to the U.S. industry. Researchers must be given the mechanisms, incentives, and training to succeed in this mission."[1]

To a growing extent, the exceptional scientific and technical development that emanates from ORNL are being translated into new American products, markets, and jobs. The Laboratory's aggressive technology transfer program is providing the catalyst for this evolution. This program recognizes the importance of face-to-face interaction between ORNL researchers and managers and their industrial counterparts.

Although our researchers are not in the business of product development, they are encouraged to become more sensitive to the potential commercial outcome of mission-related work.

Consistent with the spirit of Secretary Watkins' statement above is the introduction of Cooperative Research and Development Agreements (CRADAs). CRADAs were made possible by the National Competitiveness Technology Transfer Act of 1989 (Public Law 101-189). Martin Marietta Energy Systems, Inc., (Energy Systems) is the first DOE management

[1]James D. Watkins, Admiral, U.S. Navy (Retired), Secretary of Energy, Memorandum for Directors, Department of Energy National Laboratories; Secretarial Officers, *Policy Guidance for FY 1991–FY 1996 Institutional Planning Process*, July 6, 1990.

and operations contractor to receive the contract authority to implement CRADAs under this act.

CRADAs provide an extremely significant means for sharing the capabilities, facilities, and technologies in Oak Ridge with U.S. industry, universities, and other R&D organizations to improve our national competitiveness. In effect, a CRADA is a joint R&D mechanism. It allows ORNL to enter into cost-sharing arrangements that allow negotiated terms for handling background and resulting intellectual property, including the protection of technical data for up to 5 years. Such arrangements will be structured to leverage R&D funds both for DOE and the CRADA partner, which is particularly important in times of scarce R&D resources.

CRADAs provide the means to work together with industry, a way to "rub elbows" at the scientific bench, which is the most effective way to transfer technology. It is a person-to-person transfer of the technology, the know-how, the expertise. The Energy Systems licensing program, which has 46 licenses to date, has successfully demonstrated that technology from a national laboratory can be effectively commercialized. Most licensees, however, would like to find a way to continue the relationship with Energy Systems by tapping the expertise here, using our excellent facilities, and further developing the technology. We fully expect licenses to lead to CRADAs but also that CRADAs will result in new licenses. The two aspects of technology transfer will be highly complementary and integrated.

The gap between R&D and commercialization is one of the most difficult to bridge. It is very difficult to accomplish in the same organization and even more difficult to accomplish across organizations. CRADAs provide a means to bridge that gap. This mechanism provides industry with the opportunity to access fully the broad R&D capabilities at the DOE facilities in Oak Ridge.

It is anticipated that CRADAs will further spur economic development in the region, because close proximity enhances close working conditions. Companies that want to take full advantage of CRADAs may find Oak Ridge a good location.

Industrial Partnership Program

The Alternative Fluorocarbons Environmental Acceptability Study (AFEAS)—a consortium of the world's top chemical companies—and ORNL have joined together to fund a major international study on the total contribution of alternatives to chlorofluorocarbons (CFCs) to global climate change. To date, most attention has been focused on the direct contribution of CFCs and their alternatives to global warming, as greenhouse gases. These analyses have overlooked a major factor—savings due to energy efficiency. An objective and thorough evaluation of the energy efficiencies of options to replace CFCs in their major application areas is necessary.

This study will evaluate the relative performance, subsequent carbon dioxide emissions, and net global warming potential of all viable options to replace CFCs that can be implemented in each of the major CFC application areas on a global scale over the next 10 years. (The timeframe is defined by the CFC phaseout schedule under the Montreal Protocol.) The application areas include refrigeration, air conditioning, and heat pumps; insulation; and precision cleaning. The research team will work in cooperation with experts from industry to gather and assess the available information.

The results of this 6-month study will be made available to the United Nations Environment Programme for use in the science and technology assessments required for the 1992 review of the control provisions of the Montreal Protocol. The report will also provide important information to governments at the June 1992 meeting in Brazil, where the development of a climate convention will be discussed.

This cooperative agreement between AFEAS and DOE is the first of its type to be executed by

ORNL under the Competitiveness Technology Transfer Act of 1989.

Licensing Oak Ridge Technologies

Martin Marietta Corporation derives no benefit from technology transfer royalties. Energy Systems' Office of Technology Transfer (OTT) uses the royalty fund to further technology transfer. These uses include:

- recovering patenting and licensing costs,
- funding technology maturation projects,
- contributing to nonprofit technology transfer organizations, and
- rewarding inventors and technical staff through royalty sharing.

OTT has had success recently in developing and implementing a new policy procedure for royalty sharing. The significance of the policy procedure is that it provides substantial incentive to disclose and/or license intellectual properties. The new procedure offers improvement in incentive by

- increasing the inventor's share of royalty receipts from 10 to 15%,
- increasing the award to licensing support personnel from 4 to 5%,
- increasing the award to inventors of unlicensable-for-government-use inventions from 4 to 5%, and
- eliminating the $100,000 ceiling.

From the beginning, OTT has concentrated its efforts on those areas of technology development for which Oak Ridge has become known for excellence. The most notable area of success is in advanced materials. From superalloys to ceramics to electronic materials, Oak Ridge is internationally recognized as a leader in developing advanced materials. Other areas of commercially valuable technology include analytical instruments, waste management, intelligent systems, chemical processing, and biomedical technologies.

The initial success in granting licenses has convincingly demonstrated to industry that OTT is indeed "open for business." In fact, industry has discovered that the best way to transfer and adopt a new technology is to participate in its final stages of development. Companies have found that the most productive approach is to work in partnership with the federal facilities to develop those technologies that they find commercially promising. As expected, those firms have also found that siting a facility near the federal facilities greatly enhances the success of their business venture. Such proximity increases interactions with the technical experts, thereby reducing the technical risk in transferring the new technology.

An important goal of the Oak Ridge technology transfer program is to promote the widespread commercialization of innovations developed at ORNL, and our patent license agreements recognize the fact that a single invention can create a commercial impact across different industries. This impact is aptly demonstrated by a new solvent extraction technology developed in ORNL's Chemical Technology Division and licensed to two firms that plan to use the innovation in radically different ways. Known as the "Emulsion Phase Contactor," this patented system uses a pulsed electric field to significantly enhance the recovery of valuable products or the removal of hazardous wastes from liquid streams. One of the licensees, National Tank Company of Tulsa, Oklahoma, will incorporate this ORNL innovation into large-scale processing systems for the metals and petroleum industries. Each company that utilizes the contactor in these industries is expected to save millions of dollars in capital equipment costs, because it gives them the ability to accomplish important separations tasks in much smaller vessels. Conversely, the other licensee, Analytical Bio-Chemistry Laboratories of Columbia, Missouri, plans to commercialize the technology in a much different way. The company will develop and market bench-scale analytical laboratory

instruments that can be used for environmental compliance testing across the country. Each licensee is devoting several full-time researchers, engineers, and other technical specialists to a development effort that is expected to take about 2 years.

Other potential uses, and licenses, for this technology in the future include purification of pharmaceutical products, the separation and recovery of valuable isotopes, and the removal of hazardous wastes from liquid streams.

Business Management and Budget

A new management information system is being installed. The purpose of this system is to document and report invention status from the point of disclosure through the execution of the licensing agreement. The introduction of CRADAs will place additional demands on the management information system.

The budget for OTT in FY 1990 was $1.7 million; the number of full-time equivalents (FTEs) supported totaled 15.8 (Table 47).

Productivity Indicators

Royalty income and the number of new licenses are constantly monitored and reported (Tables 48 and 49). These data provide important measures of tactical success. However, the measure for the strategic success, with respect to the OTA mission, is the dollar value of product sales resulting from our licensing agreements. Product sales ending FY 1990 will exceed a cumulative total of $30 million (Figs. 55–58).

OTT plans to execute 18 new licenses in FY 1991. Additionally, OTT anticipates that royalty income will exceed $1 million.

The implementation of CRADAs will require additional productivity indicators to monitor and report OTT plans to implement 20 CRADAs in FY 1991 with a total value of $5 million.

Another important measure that reflects the value and quantity of ORNL's interactions with others is the increasing trend in technical publications (Fig. 59).

Table 47. Estimated staffing and expenditures for the Office of Technology Transfer[a]

	Fiscal year							
	1989	1990	1991	1992	1993	1994	1995	1996
Funding ($ in millions)								
OTT	1.29	1.66	1.96	2.05	2.14	2.23	2.39	2.48
Staffing (FTEs)								
Professional								
OTT	10	11	11	11	11	11	13	13
Support	4.8	4.8	5	5	5	5	5	5

[a]Data are provided for the Martin Marietta Energy Systems, Inc., Office of Technology Transfer, which includes ORNL, the Y-12 Plant, the Oak Ridge K-25 Site, and Paducah Gaseous Diffusion Plant.

Table 48. Office of Technology Transfer licenses executed (FY 1990)

Licensee	Technology
Apache Corporation	Triple Effect Absorption Chiller
Micro Safe-T Systems	Layered Protection System
Analytical Bio-Chemistry Labs	Solvent Extraction
NATCO	Solvent Extraction
Sematech	Microwave Plasma Source for Etching
Scintillation Technologies Corp.	Iridium Generator
Spectrum Technologies USA, Inc.	Motor Current Analysis Method
Sorrento Electronics	Groundwater Cerenkov Radiation Detector
Keramont Corporation	SiC Whisker Reinforced Ceramics

Table 49. Technology transfer results

	Fiscal year		
	1988	1989	1990
Patent application	36	32	25
Patents granted	26	35	27
Licenses issued	12	9	13
License income[a]	204	228	500

[a]Dollars in thousands.

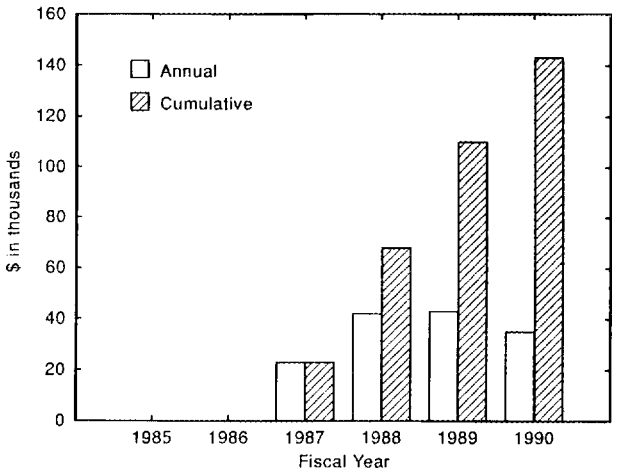


Fig. 56. Royalties paid to employees.

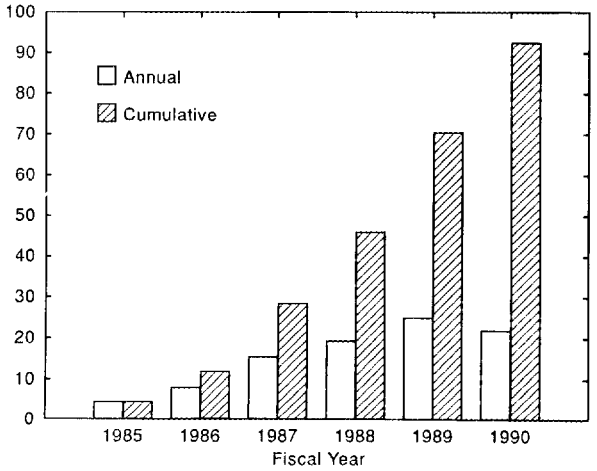


Fig. 55. Rights received from DOE.

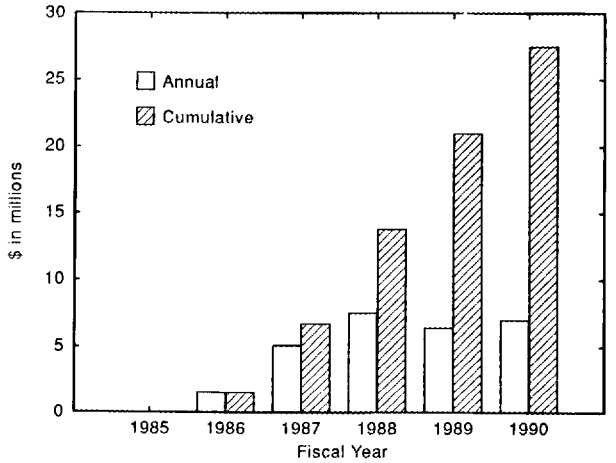


Fig. 57. Licensed product sales.

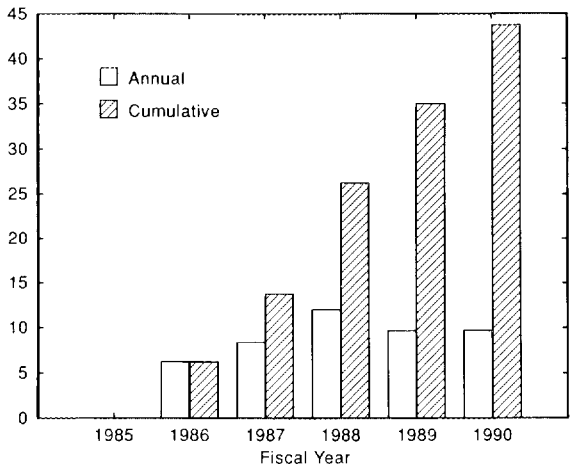


Fig. 58. Active licensing agreements.

Subcontracting and Procurement

Subcontracting increased in FY 1990 because of an increase in environmental restoration activities. This trend should continue through the early 1990s (Table 50). The increase in transfers to other DOE facilities in FY 1989 and the subsequent decrease in FY 1990 (Table 51) resulted from the changing level of effort associated with the cesium stabilization work performed at DOE's request for the state of Georgia.

Table 50. Subcontracting and procurement by fiscal year
($ in millions)

	1989	1990	1991
Subcontracts and procurement with universities	18.7	19.4	19.8
All other subcontracts and procurements	112.4	118.4	129.6
Transfer to other DOE facilities	12.9	7.0	3.8
Total	144.0	144.8	153.2

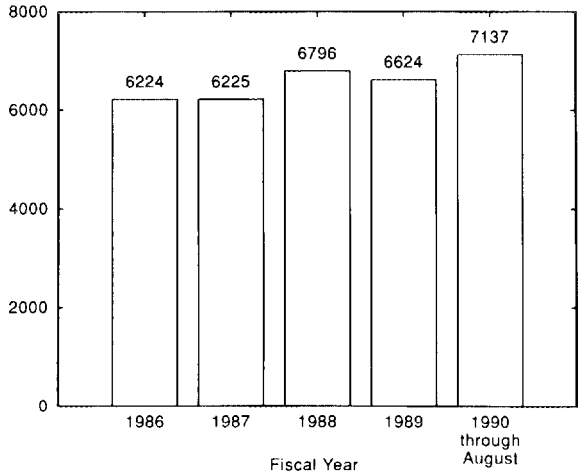
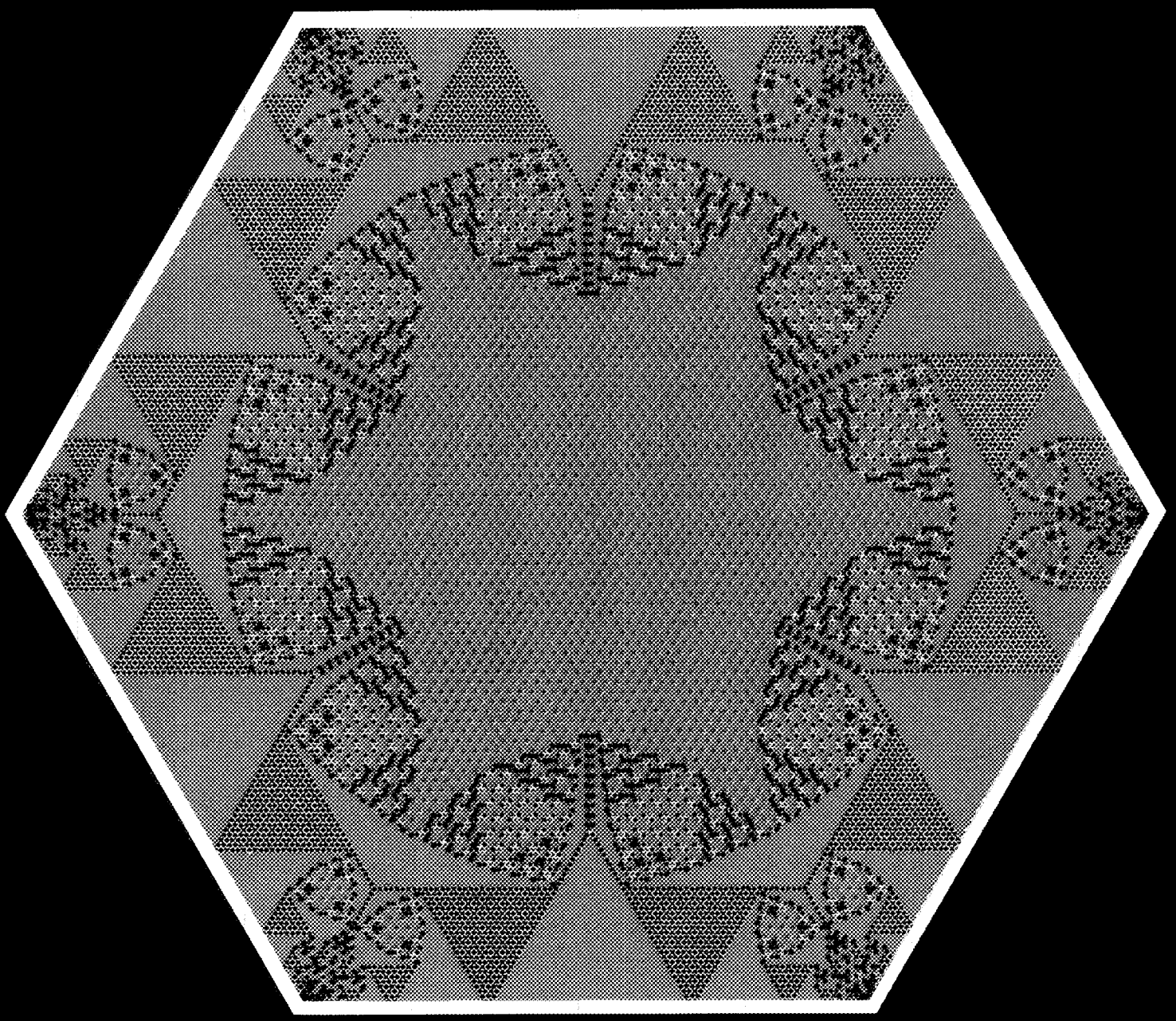


Fig. 59. Technical publications.

Table 51. Small and disadvantaged business procurement
($ in millions)

	Fiscal year	
	1989	1990
Procurement from small and disadvantaged business	63.7	52.2
Percent of total procurements	38.7	35.6

Human Resources



Human Resources

Laboratory Personnel

The diverse nature of the work performed at ORNL demands a high-quality, multidisciplinary technical staff and an equally skilled support and services staff. Scientists and engineers constitute the bulk of the Laboratory's professional staff, representing about 70% of the total number (Table 52). Of the 777 professional scientists on staff, 496 (or 64%) hold a Ph.D. Among engineers, 249 of the 824 (or 30%) on staff hold Ph.D.'s; master's degrees are held by another 382 (or 24%) professional scientists and engineers. About 88% of the total professional staff hold bachelor degrees or higher.

The engineering disciplines represented by our staff are primarily chemical, mechanical, and nuclear. There are also about 30 mathematicians, about 456 other physical scientists, about 235 life scientists (biomedical and environmental), and about 30 social scientists. ORNL is also supported by Martin Marietta Energy Systems central organizations, including Engineering; Computing and Telecommunications Division (C&TD); Information Resources and Administration (IRA), which includes library, technical publications; graphic arts, and printing support; and Procurement. Currently, about 326 engineering staff, 276 C&TD staff, and 233 IRA staff support and contribute to ORNL programs.

The average age of all ORNL employees is 43.7 years, and the average years of service is 14.8. The average age has increased slightly since 1985 (from 43.4 years), while the length of service has decreased (from 15.1 years). In 1989, the number of new hires (416) exceeded the number of separations (408), resulting in an addition rate of 7.6% and a separation rate of 7.8%. In 1987 and

Table 52. Oak Ridge National Laboratory staff composition (CY 1989)

	Ph.D.	MS/MA	BS/BA	Other	Total
Professional staff					
Scientists	496	139	129	13	777
Engineers	249	243	272	60	824
Management/administrative	107	75	90	30	302
Other	31	73	108	178	390
Total professional staff	883	530	599	281	2293
Support staff					
Technicians	0	7	93	430	530
Union employees (includes crafts, laborers, etc.)	0	1	8	988	997
Administrative/clerical	0	2	66	648	716
Other (i.e., supervisors of union employees)	0	0	6	86	92
Total support staff	0	10	173	2152	2335
Laboratory total staff	883	540	772	2433	4628

1988, the addition rate (12.4% and 11.5%, respectively) was significantly higher than the separation rate (6.7% and 8.4%, respectively).

Improving and Maintaining Continuity of Staff Quality

The Laboratory had a 72% acceptance rate for employment offers made to persons with Ph.D.'s during 1989. This rate has increased from 66% in 1988. The acceptance rate for B.S. and M.S. candidates has also increased this year from 66% to 70%. However, the competition for outstanding scientists and engineers is increasing. To ensure the continued high caliber of those being hired, the Laboratory has established a set of hiring guidelines that defines the academic and professional characteristics being sought in new hires. Additionally, an ad hoc review process has been re-instituted for prospective Ph.D. new hires and for experienced B.S. and M.S. technical candidates.

To ensure continuity in both staff quality and capability, the Laboratory recognizes that it is necessary not only to attract and hire outstanding personnel but also to retain them. ORNL strives to provide a suitable environment for research, to provide opportunity for growth, and to reward excellent performance. Several financial and nonfinancial incentive and recognition programs have been established to reward outstanding contributions and significant achievements. ORNL participates in Energy Systems annual awards night to recognize outstanding performance in various categories: publications, technical achievement, management support service, inventions, operational performance, and administrative/technical support.

Numerous studies have addressed the changing demographics of the country's work force (e.g., *Workforce 2000*), especially as it relates to those being trained in the sciences, and have suggested that a more culturally diverse work force is on the horizon. As more of these workers enter the job market, it will be necessary to adopt less traditional approaches to personnel management. It is projected that by the year 2000 over half of those entering the work force will be women, minorities, or the disabled. The Laboratory, and Energy Systems as a whole, are already instituting some changes in personnel policies that will be required to meet the somewhat different demands of this changing work force. For example, the company's revised part-time policy and the concept of employee convenience time both allow employees greater flexibility in the scheduling of work hours. Additional work force issues are also being identified and considered by an Energy Systems and Martin Marietta Corporate task force. ORNL is also proposing enhanced recruiting and marketing efforts to target women and minorities.

As mentioned earlier, disabled Americans will probably assume a greater role in the work force in the future. The Laboratory will continue its heightened emphasis on recruiting and hiring qualified disabled candidates. Energy Systems President Clyde Hopkins, who is serving as a member of the Executive Committee of the (U.S.) President's Committee on the Employment of People with Disabilities, provides leadership in this area. Energy Systems recognizes the potential for significant change in our disability program overall relative to proposed civil rights legislation for the disabled.

Special Personnel Programs

Among the special personnel programs sponsored by the Laboratory, the Educational Assistance Program remains the best tool for helping employees achieve their academic and career goals. In 1989, over 800 employees participated in the Educational Assistance Program. This program helps ensure the proper

availability, optimum utilization, and continuing welfare of Laboratory employees.

The Laboratory also provides in-house development programs designed to meet the specific education and training needs of its current population. Further, the Laboratory is responding to a heightened emphasis on environmental, safety, and health issues by expanding specialized technical training programs. Finally, the cadre of courses offered as a part of ORNL's management training is being expanded to include courses that present strategies for communicating across cultural barriers and cultural diversity. This area of management training is crucial in preparing managers for the changing work force that will be emerging in the 1990s.

Affirmative Action (AA) is an integral part of all personnel functions and activities for the Laboratory. The ORNL AA office is a department within the Human Resources Division, and the AA Program Site Manager reports directly to the ORNL Human Resources Director. A primary responsibility for the AA Program Site Manager is to monitor AA activities and to inform Laboratory management about progress made in hiring and promoting minorities and women. The site manager also monitors and keeps management aware of areas of concern relative to the program (e.g., the inability to meet a hiring goal, or on-staff representation of minorities or of women that is below the calculated availability). Overall, the Laboratory's representation of minorities has remained fairly constant, increasing slightly over the past few years. The representation of women on staff has continued to increase, with a similar increase in upward mobility (i.e., in the numbers being promoted to higher levels and into management).

Upward mobility for minorities is receiving special attention from Laboratory management. The Laboratory has undertaken additional recruiting efforts to increase the size of the feeder pool from which minority candidates for management openings can be drawn. Plans are being prepared for salaried minorities in an effort to identify areas for growth and development. Also, the formal mentor program, though it makes no guarantees of promotion, can provide increased visibility for an employee, either within his/her own area of work or outside of it, depending on the mentor selected. This year eight ORNL employees, primarily women and minorities, participated in the program. The program provides an opportunity for each participant to become better acquainted with the larger Energy Systems organization. Further, it is hoped that through the interactions necessitated by these mentorships, employees will gain additional insights that will be useful in developing their own career plans.

Exploratory R&D Program

The principal objective of the ORNL Exploratory Studies Program is to provide financial support for innovative R&D ideas that, while within the general mission of the Laboratory, have no direct programmatic funding. Such ideas could lead to productive new technical directions for the Laboratory, DOE, and the nation. The program obtains its funds from DOE through an overhead charge to all other Laboratory programs. The program operates under the authority of DOE Order 5000.1A, "Institutional Planning by Multipurpose Laboratories," dated September 12, 1986.

There are two major activities within the Exploratory Studies Program: the Seed Money Fund and the Director's R&D Fund. The Seed Money Fund is the continuation of the original ORNL Seed Money Program that was initiated in 1974; the Director's R&D Fund was added in 1983. The approved FY 1990 budget was $9.0 million for the ORNL program, with $2.1 million allocated for the Seed Money Fund and $6.9 million allocated for the Director's R&D Fund. This total amounts to approximately 1.9% of the total operating budget for ORNL. Table 53 lists authorized funding for

FY 1988, 1989, 1990, and 1991 (projected).

Proposals for Seed Money Fund projects are accepted directly from the Laboratory's scientific and technical staff (with management concurrence) at any time of the year, are peer reviewed, and are selected for funding with the assistance of a

Table 53. Authorized exploratory R&D funding ($ in millions)

Fiscal year			
1988	1989	1990	1991[a]
5.1	7.0	9.0	9.0

[a]Estimated.

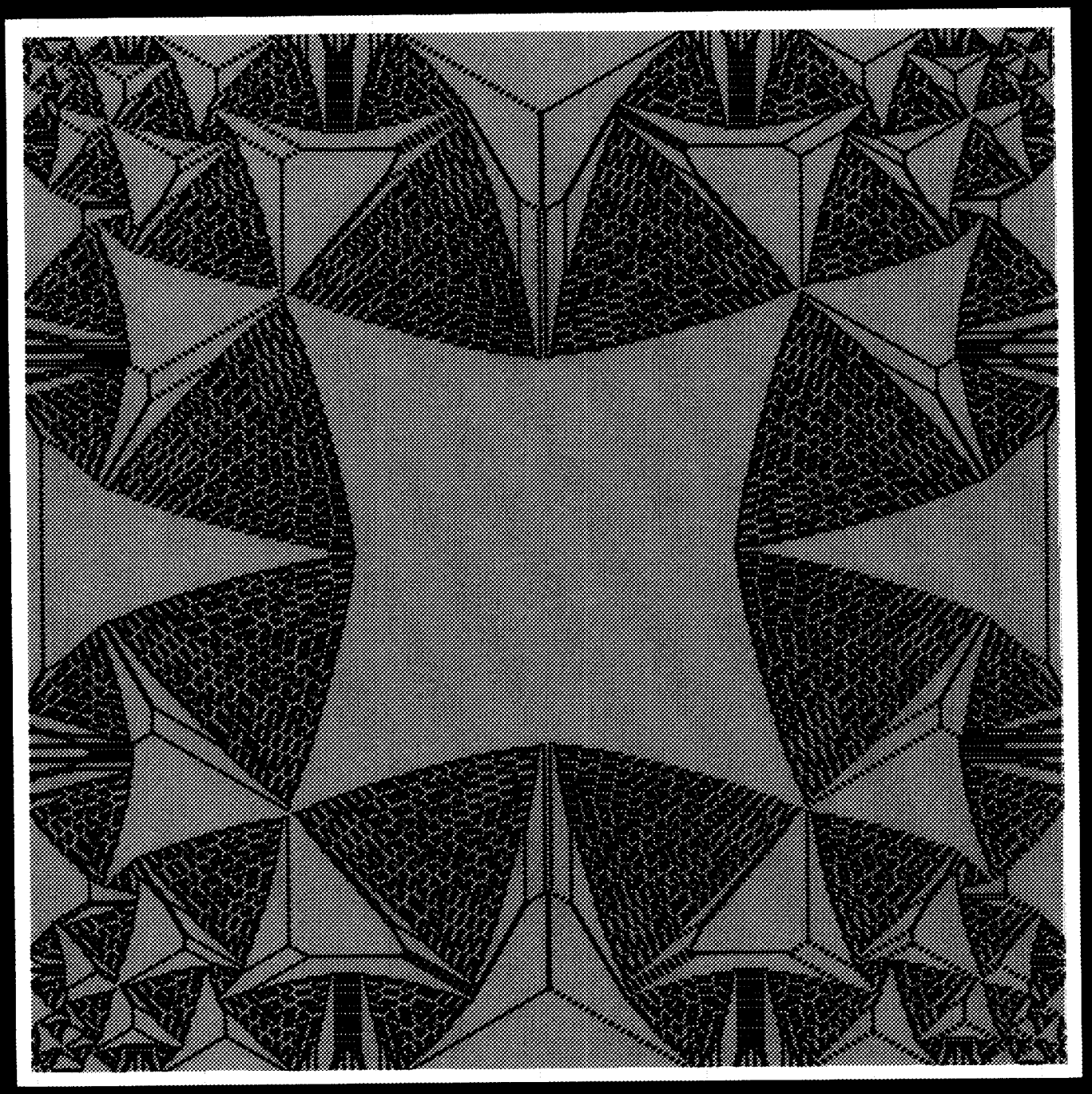
Proposal Review Committee composed of representative scientific and technical staff. The 1-year projects are generally funded at less than $100,000. Director's R&D Fund proposals are solicited from the scientific and technical staff in June, reviewed through line management, and most are selected by the Laboratory's Executive Committee. These projects may continue for up to 3 years at levels of $300–400 thousand per year. Ten percent of the Director's R&D Fund is allocated individually by the Laboratory Associate Directors. Providing two routes of access to exploratory funds maximizes the likelihood that novel and seminal ideas originating from the staff will be recognized and supported.

The Exploratory Studies Program is administratively part of the ORNL Office of Planning and Management. The position of manager rotates every 2 years among members of the scientific and technical staff of the Laboratory. Additional descriptions of ORNL's Exploratory Studies Program can be found in three recent DOE publications:

- *Accomplishments of the Oak Ridge National Laboratory Seed Money Program*, DOE/ER-0274 (1986);
- *A Review of the Oak Ridge National Laboratory Seed Money Program*, DOE/ER-0319 (1987); and
- *A Review of the Exploratory Research and Development Programs at the Five Multiprogram Energy Laboratories*, DOE/ER-0361 (1988).

The program operates efficiently and is held in high regard both internally and externally. For all divisions the overall return of new work for the Laboratory, calculated through October 1, 1989, is approximately four times the program's investment. The program provides the scientific and technical staff with morale-boosting incentives to be innovative. A high percentage of honors, awards, and new programs at the Laboratory has originated through work supported by the Exploratory Studies Program.

Site and Facilities



Site and Facilities

Laboratory Description

ORNL is a large, multiprogram energy research laboratory with projects that cover diverse scientific and engineering disciplines. These programs create demands for a variety of building and equipment needs, including specialized experimental laboratories and a large complement of office space. Along with these are needs for major utility and waste-disposal facilities. In addition, the everchanging description and set of programs that result from the nature of developmental research and evolving national energy priorities require a high degree of flexibility in the utilization of the Laboratory's facilities.

Currently, the Laboratory occupies ~2.6 million ft^2 of building space at the main Bethel Valley site and the Melton Valley site to the south. In addition, over 1 million ft^2 of building space at the Oak Ridge Y-12 Plant are allocated to the Laboratory, and ~200,000 ft^2 of space are occupied by ORNL personnel at the Oak Ridge K-25 Site.

ORNL has full facilities' responsibility for its main site and surrounding areas. However, for the facilities at the Y-12 Plant, ORNL has full responsibility for building maintenance but only limited responsibility for supporting utilities. At the K-25 Site, the Laboratory has minimal responsibility for buildings and supporting utilities, because both are shared with other tenants.

In recent years, continued growth in ORNL staff, visiting researchers, and guests, along with transfer of a number of DOE personnel to the Laboratory site, has forced the use of many temporary trailer facilities as well as the use of local off-site rental space.

Because the Laboratory site and facilities were originally developed as part of the Manhattan Project and have evolved to the present under insufficient facility modernization budgets to permit needed building replacement, the average age of Laboratory buildings has been steadily increasing, and the condition of building space and supporting utilities has been declining. Figures 60 through 65 illustrate the current distribution, use, age, condition, and size of ORNL buildings. Table 54 lists estimated facility replacement values. The replacement estimates are based on currently active functions and do not include replacement of obsolete facilities or costs associated with decontamination and decommissioning of existing facilities.

Although past funding limitations have not permitted major upgrades over large portions of the Laboratory site, some of the least desirable space has been replaced through construction projects supported by general plant project (GPP) funds. Also, past approval of a limited number of major line-item requests has permitted construction of some important new research buildings and significant restoration of utility systems. However, much more must be accomplished to provide the kind of facilities conducive to producing the highest quality research programs.

In addition, over the years, ORNL has employed a number of major experimental facilities to conduct its programs. Nuclear reactors, radioisotope production facilities, and centrifuge enrichment facilities have supported many important aspects in the development of this nation's nuclear energy, nuclear medicine, and research capabilities. Now that the useful life of some of these facilities has been expended, the Laboratory is faced with significant expense for current surveillance activities and eventual decontamination and decommissioning. A major

Table 54. Estimated facilities replacement value

Facilities type	Replacement cost range[a]	
	Lower	Upper
Buildings and structures	640	940
Reactors	1,100	1,500
Process facilities	440	660
Accelerators	260	390
Utility systems	220	320
Roads, bridges, and parking	130	160
Security facilities	5	10
Automatic data processing equipment	60	85
Motor vehicles	10	15
Heavy equipment	5	10
Other equipment and facilities	30	50
Subtotal, fixed price construction	2,900	4,140
Engineering (35%)	1,015	1,450
Construction support services (20%)	580	830
Operation readiness review (2.5%)	70	100
Construction manager (15%)	435	620
Subtotal	5,000	7,140
Contingency (40%)	2,000	2,860
Total	7,000	10,000

[a]In millions of FY 1990 dollars.

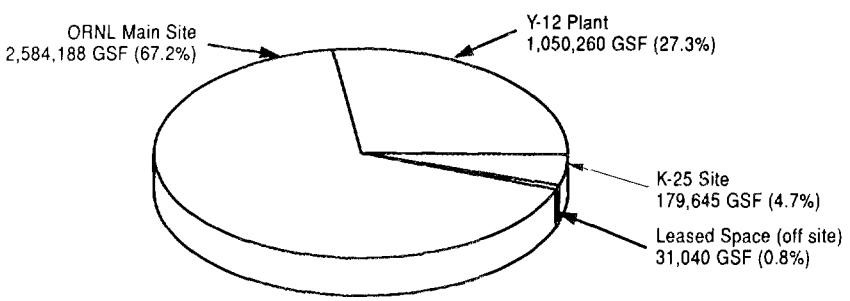


Fig. 60. Laboratory space distribution—location and building area in gross square feet (GSF).

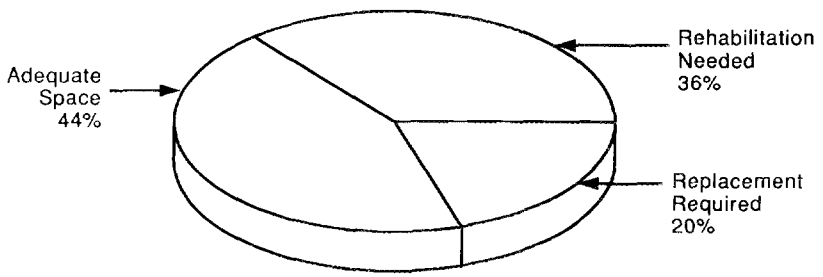


Fig. 61. Condition of Laboratory space by percentage.

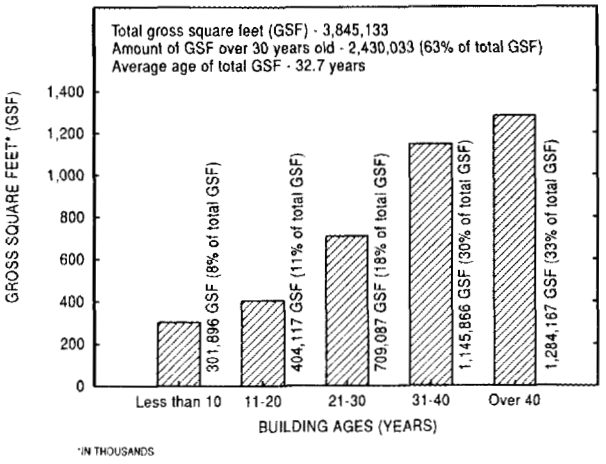


Fig. 62. Gross square footage of Laboratory buildings—categorized by age.

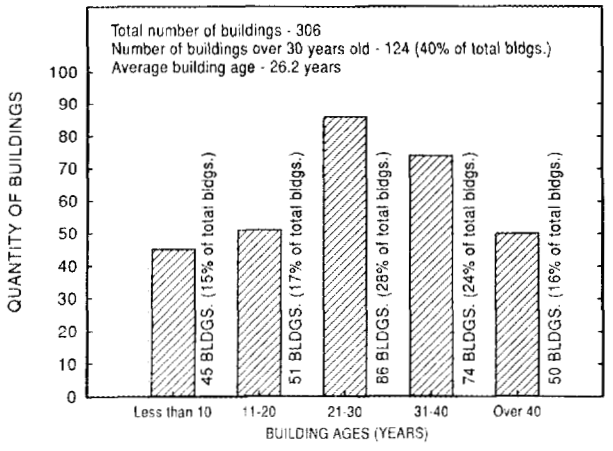


Fig. 63. Distribution of Laboratory buildings by age.

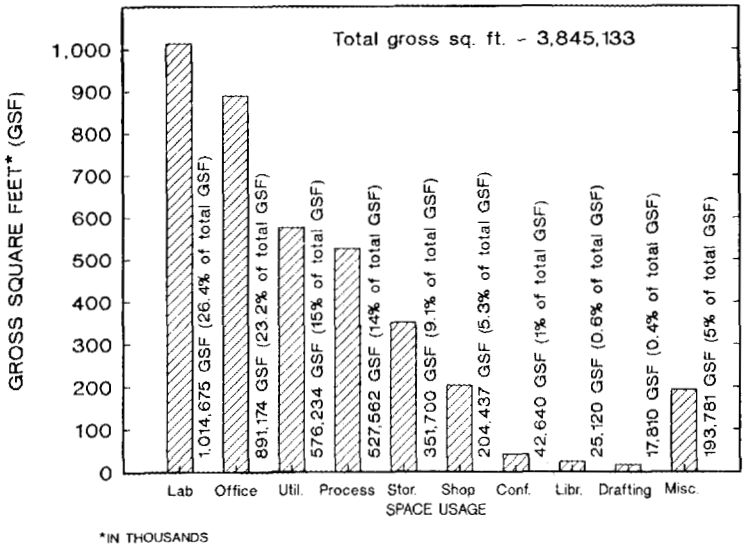


Fig. 64. Use of Laboratory space.

funding commitment will be required to properly dispose of these inactive facilities.

A major concern is that DOE funding support for all forms of nonenvironmental capital projects and equipment has declined significantly over the last several years. Figure 66 shows that capital funding at ORNL has declined by more than 40% between FY 1984 and FY 1990, not including the effects of inflation, which worsen the trend.

Facilities Plans and Options

The objectives of ORNL's site and facilities development plans are to provide high-quality space, reliable utility support, and the additional necessary infrastructure required to produce the appropriate environment for conducting

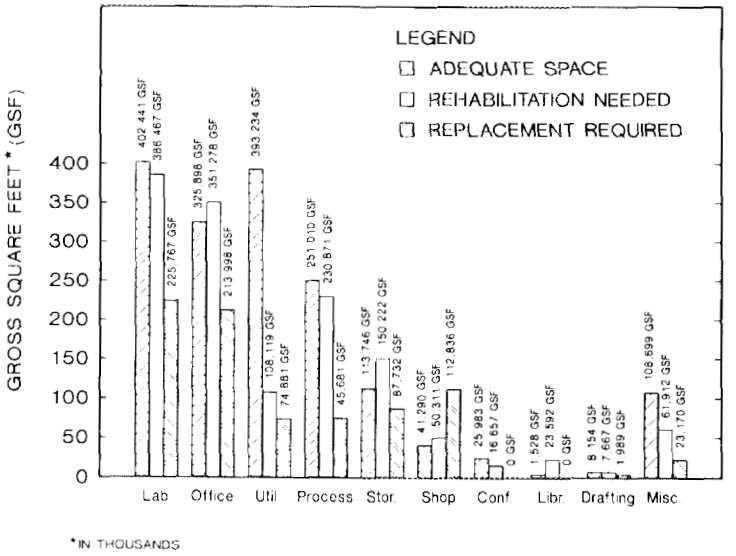


Fig. 65. Condition of Laboratory space—categorized by use.

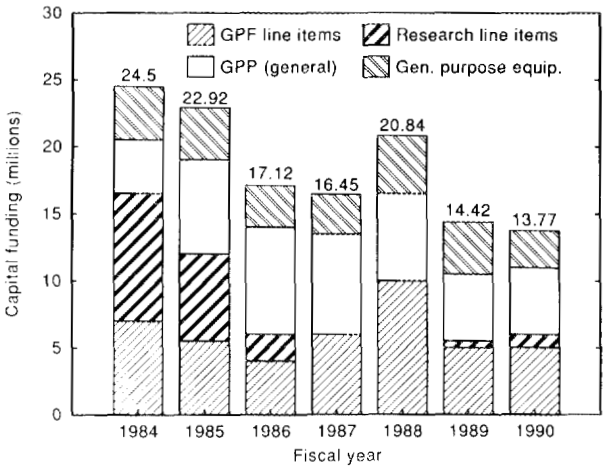


Fig. 66. Nonenvironmental capital funding.

outstanding research on DOE programs. To achieve this goal, it is crucial that capital assets planning be closely coupled to the Laboratory's technical program objectives and plans as described in this document.

In response to recognized national needs, the Laboratory's strategic directions have been set to address three primary themes:

- energy research and development (R&D);
- environmental studies; and
- improved competitiveness of the United States in the international marketplace.

In support of both energy R&D activities and improved U.S. competitiveness, three major programmatic facilities are required:

- an Advanced Neutron Source (ANS) to serve as the world's most powerful neutron research facility;

- the Center for Biological Sciences to establish an efficient, consolidated research center for biology programs; and
- a Materials Science and Engineering Complex to provide state-of-the-art research facilities for materials programs.

All three of these facilities will include a strong focus on technology transfer through establishment of user facilities and educational activities through joint programs with universities.

Another major facility required for environmental protection purposes is the Waste Handling and Packaging Plant. This facility will conduct radioactive waste solidification operations and packaging for shipment to the national disposal site.

The Laboratory has placed high priority on two other new building projects:

- an Advanced Computing Technology Center to provide a first-class computing capability to support research programs; and
- a Technology Transfer Center to establish improved links with both educational institutions and private industry while simultaneously providing training facilities for ORNL staff.

Finally, a major new project is proposed to allow extensive renovations and rehabilitation of general-purpose buildings and utility systems that have gradually deteriorated over the past 40-plus years (see Initiatives section). This initiative must be supplemented with a vigorous program to dispose of inactive experimental facilities that have exceeded their useful life and that currently require continual surveillance to ensure safe shutdown.

Facilities Resource Requirements

As the Laboratory's site and facilities planning staff progress in the preparation of a comprehensive ORNL Site Development Plan, many of the Laboratory's construction project needs are being identified. A current list of major construction projects is presented in Table 55. These construction activities would provide a major step in ORNL's site and facilities modernization efforts.

Computing and Telecommunications Requirements

Accomplishments in FY 1990

Fiscal year 1990 can be characterized as a year in which the foundation was laid for many future enhancements in computing and telecommunications at ORNL. The year's developments reflected some basic changes in the way people approach computing and the way technology can answer their needs. ORNL took deliberate and necessary steps to begin addressing its primary computing goal: to provide a computing environment that is among the best in the country.

During FY 1990, the *Strategic Plan for Computing at Oak Ridge National Laboratory*[1] was updated. The plan's 34 goals outline a course of action for the next 5 years in the areas of computing research, scientific computing, administrative computing, management of computing resources, and training. Also included are discussions of users' roles, ORNL opportunities in the federal High Performance Computing Initiative, the benefits of computing standards, a summary of ORNL's existing computing resources, and a comparison of this year's goals and those in the previous year's plan.

[1]Office of Laboratory Computing, *Strategic Plan for Computing at Oak Ridge National Laboratory*, FY 1991–1995, ORNL/PPA/INT-90/3, August 1990.

Table 55. Major construction projects[a]
($ in millions)

	Fiscal year								Total estimated cost[b]
	Funded construction		Budgeted construction	Proposed construction					
	1989	1990	1991	1992	1993	1994	1995	1996	
Research program projects[c]									
Advanced Neutron Source (design phase)				37.7	36.6				74.3
Advanced Neutron Source (construction)						TBD[d]	TBD	TBD	675–850
Heavy Ion Storage Ring for Atomic Physics				8.3	6.9	4.4			19.6
Upgrade Mammalian Genetics Facility, air supply				0.6	3.5				4.1
Center for Biological Sciences					4.0	20.0	20.0	3.9	47.9
Waste Handling and Packaging Plant					32.0	60.0	103.0	23.0	245.0
Center for Advanced Microstructual Analysis					3.0	12.0	14.5	8.0	37.5
Solid State Sciences Building						3.5	14.5	10.0	28.0
Center for Study of Advanced Materials[e]				2.0	14.0				16.0
Advanced Photonics Laboratory						1.5	5.2		6.7
Earth Systems Facility						2.0	7.0		9.0
Environmental compliance projects									
Bethel Valley LLW-CAT system upgrade	11.8	11.4	7.9	0.1					35.0
Melton Valley LLW-CAT system upgrade				4.5	15.9	11.5	9.1		41.0
Waste Characterization and Certification Facility					2.5	9.5	4.0		16.0
Decontamination Facility						3.0	14.0	6.0	23.0
Bethel Valley FFA upgrades						7.0	12.0	11.0	30.0
Dry cask storage						3.5	14.5	9.0	27.0
Multiprogram general-purpose facilities (KG)									
Buildings/facilities/revitalization									
A. Replace substandard housing									
Measurements and Controls Support Facility		0.9	3.1		0.4				4.4
Central Research and Support Building					4.5	6.0	1.6		12.1
Maintenance support and decontamination laundry					2.6	8.0	5.4		16.0

Table 55 (continued)

	Fiscal year								Total estimated cost[b]
	Funded construction		Budgeted construction	Proposed construction					
	1989	1990	1991	1992	1993	1994	1995	1996	
Safeguards and Security Building									15.0
B. Renovate serviceable structures									
Piping system restoration, ORNL at Y-12	0.6								3.8
Building piping system upgrade, ORNL at Y-12	1.33								1.85
Upgrade fire protection, ORNL at Y-12	0.74								1.75
Reroofing					3.0	6.0	6.0		15.0
Refurbish building exteriors, ORNL at Y-12 Plant						2.0	3.5	2.0	7.5
Restore Central Research Complex							10.0	20.0	60.0
Upgrade building HVAC systems, phase I					3.0	9.0	3.0		15.0
Upgrade building HVAC systems, phase II							5.0	10.0	25.0
Refurbish metallurgical hot cells									50.0
C. Upgrade capabilities									
Advanced Computing Technology Center							3.0	7.0	15.0
Technology Transfer Center									20.0
Environmental, safety, and health protection									
A. Environmental Protection									
Nonradiological Wastewater Treatment Plant	1.1								
Replace oil-filled transformers						2.0	2.3		4.3
Upgrade coal yard runoff treatment facilities							1.0	1.0	2.0
Steam plant emissions improvements								3.0	15.0
B. Safety									
Road safety improvements	1.65	0.87							2.5
Fire protection upgrade		1.3	2.0						3.3
Health physics instrumentation upgrade					4.0	8.7	6.0		18.7
OSHA compliance-programmed expense activities				40.0	40.0	40.0	40.0	30.0	190.0
OSHA Compliance, phase I					5.0	8.0	7.0		20.0
OSHA Compliance, phase II							10.0	20.0	80.0

Table 55 (continued)

	Fiscal year								Total estimated cost[b]
	Funded construction		Budgeted construction	Proposed construction					
	1989	1990	1991	1992	1993	1994	1995	1996	
OSHA Compliance, phase III								10.0	100.0
C. Health									
Radiation Exposure Assessment Laboratory					3.0	9.0	8.0		20.0
Utility restorations									
Electrical system upgrade		0.8	1.4	0.1					2.3
Upgrade Steam Distribution System, west end				1.1	6.0	1.9			9.0
Sanitary Sewerage System					2.0	5.0	4.0		11.0
Potable Water System						2.5	6.0	3.5	12.0
Fire Water System						1.0	3.0	1.0	5.0
Electrical substations, switchgear, and distribution system							3.0	8.0	18.0

[a]Construction data as of November 1, 1990, for research program and environmental compliance projects and November 16, 1990, for multiprogram general-purpose facilities.

[b]TEC is tentative until conceptual design report (CDR) has been completed on each project.

[c]Does not include accelerator and reactor improvements and modifications projects or NPR construction funding.

[d]To be determined.

[e]Joint initiative with Southeastern University Research Association (SURA).

In January 1990, ORNL acquired the world's first Intel iPSC/860 parallel supercomputer. The 128-processor machine is being used to address grand challenges in such fields as materials science and high-energy physics. In addition, it serves as a useful tool in computer research on parallel architectures.

At the other end of the computing spectrum, FY 1990 saw unprecedented growth in the number of computing workstations at ORNL. Major reasons for this growth were the following:

- the announcement of a workstation price agreement, based on a fully competitive bid and designed to streamline the procurement process for several categories of workstations;
- the introduction of powerful high-end workstations from several major vendors that went far beyond any previous performance capabilities; and
- the availability of powerful entry-level workstations that could be purchased with operating funds.

These developments resulted in doubling the number of computer workstations at ORNL in FY 1990.

At the same time, the utility of the large number of personal computers (PCs) has been enhanced by the selection of Banyan VINES as the supported Network Operating System providing mail and other network services to the PC.

One important milestone in FY 1990 was the completion of the conversion to UNICOS (Cray's UNIX) on the Cray X-MP. This was the first major central resource used by ORNL to employ open systems. Open systems are computing and communications facilities that conform to standards, independent of any vendor's proprietary architecture. The open systems market offers the

industry's most competitive prices. Also, by their conformance to standards, these systems permit software portability and transparent networking. The trend is toward enhanced open systems for ORNL in the future.

Three other central systems were upgraded during FY 1990. A DECsystem 5810 replaced an interim VAX 785. This system now provides highly interactive, widely available UNIX capacity. At the end of FY 1990, the two IBM 3033 systems were replaced by an IBM 3090-150e. This system will provide both MVS and AIX operating systems. A cluster of 2 VAX 8650s was replaced with a more modern VAX 6000-420 system, providing a VMS environment.

One of the most important developments in data communications was the establishment of the External Communications Ethernet Segment (ECES). ECES acts as a central entry point for external networks, which provide the ability to transfer files and to log in to tens of thousands of computers at numerous universities, national (or federal) supercomputer centers, and other laboratories.

Central data storage capacity took a significant step with the acquisition of an Automated Data Library that is capable of storing 1.2 TB (terabytes) of data. This equipment automatically mounts data on request from the user.

Trends for the Near Term

As outlined in the *Strategic Plan for Computing*, the main trends in the near future concern the use of computing standards and open systems, the proliferation of distributed computing and desktop resources, and a greater emphasis on training to help people adjust to the new computing technologies and tools.

The *Strategic Plan* provides leadership in the area of computing standards by identifying the rapidly growing number of widely accepted computing industry standards. This positions ORNL to take advantage of lower software and hardware costs existing in the open systems marketplace and reduces our dependence on a few vendors.

The introduction of more workstations enables scientists and researchers to take advantage of distributed computing. The ability to allot programs to various computers on the network and to use files throughout the network transparently lets people match the task to the computing resource. For example, using distributed computing, a scientist can assign number-crunching tasks to a supercomputer, visualization to a desktop workstation, and storage to a central file server. To provide this latter function, the Automated Data Library will be incorporated into a network-based file server.

The availability and quality of computer training will be a major factor in enabling ORNL staff to exploit new computing resources. An unprecedented number of upcoming changes in the local computing environment point to the need for specific training goals. These goals must address changes brought about by the replacement of the IBM 3033s and the DECsystems, the growing use of technical workstations, the proliferation of the X Window System and related graphical user interfaces, and the potential of distributed applications.

Future Trends

The federal government has developed a plan for a High-Performance Computing (HPC) Program. The goals of the plan are to:

- maintain and extend U.S. leadership in high-performance computing and encourage U.S. sources of production;
- encourage innovation in high-performance computing technologies by increasing their diffusion and assimilation into U.S. science and engineering communities; and
- support U.S. economic competitiveness and productivity through greater utilization of high-performance computing in analysis, design, and manufacturing.

During the last decade, large-scale computation has come of age as a useful tool for the simulation of complex physical systems. The computational paradigm now complements scientific experiment and theory, especially when theory is too inaccurate and experimentation is too expensive, dangerous, fast, or slow. The concept of the grand-challenge problem has become important because it is now possible to envision truly massive computations that can contribute significantly to the solution of problems with national impact.

Because of the breadth of research at ORNL, there is expertise in a number of potential grand-challenge areas. ORNL could participate in the HPC Program by proposing to establish a Center for High-Performance Computing to address a spectrum of grand-challenge problems using one computing architecture. Any such proposal would include alliances with other research laboratories, universities, computer vendors, and the state of Tennessee. In addition, unique regional institutions, such as the Tennessee Valley Authority, could play a role. An industrial affiliates program and a technology-transfer program would be important for making the resources of this center more widely available.

Ideally, this Center should include a range of systems, from prototypes to mature machines. These resources should be updated or replaced frequently to reflect industry developments and the implementation of innovative hardware and software concepts. To facilitate the effective use of the equipment, the Center should be accessible through fiber-optic, wide-area networks.

The Center is also conceived to be a vehicle for improving education at all levels, from preschool to graduate school, and it could provide resources to enhance existing and planned ORNL education programs. In partnership with various schools, the Center could place resources in schools that would provide students with wider access to information and computation.

ORNL management supports Laboratory participation in the HPC Program. Resources that could become available to ORNL researchers through the HPC program as early as 1993 would significantly exceed any resources that are available today. To this end, ORNL has included in its financial planning a major $30 million system for FY 1993.

Appendix: Resource Projections

Table A.1. Laboratory funding summary
[$ in millions[a]—budget authorization (BA)]

	Fiscal year							
	1989	1990[b]	1991[c]	1992[c]	1993	1994	1995	1996
DOE	337.7	364.2	485.6	545.3	446.9	438.0	444.5	442.5
Work for Others[d]	92.2[e]	91.4	122.9	121.6	100.7	103.1	102.9	103.7
Total operating	429.9	455.6	608.5	666.9	547.6	541.1	547.4	546.2
Capital equipment	14.1	16.2	29.3	32.6	28.1	26.1	25.9	20.9
Program construction Funded/budgeted	12.5	20.2	18.2					
General-Purpose Facilities Funded/budgeted	5.4	3.9	6.5					
General Plant Projects (AT, GF, KG)	12.1	10.5	8.2	16.0	40.2	15.0	15.0	15.0
General Purpose Equipment (AT, KG)	3.4	3.4	3.8	11.4	11.5	11.5	11.5	11.5
Total Laboratory	477.4	509.8	674.5	726.9	627.4	593.7	599.8	593.6
Proposed construction								
Program			2.8	67.0	131.6	TBD[f]	TBD[f]	TBD[f]
General-Purpose Facilities				41.2	73.5	109.1	127.8	115.5
Total projected funding	477.4	509.8	677.3	835.1	832.5	TBD[f]	TBD[f]	TBD[f]

[a]4.5% escalation from 1990–1991 and 1991–1992. 1993–1996 = constant 1992 dollars.

[b]Applied Technology Division included beginning in 1990.

[c]Includes two FWPs proposed in 1991 budget submission to cover OSHA and other safety and health compliance needs.

[d]Includes Nuclear Regulatory Commission. In addition, there are a few WFO projects that have ORNL staff as principal investigators, but part of the funding is reported through the Y-12 and K-25 financial plans. In 1990, about $5.3 million of ORNL-managed WFO was reported through the other two financial plans and is not included in the above table.

[e]Includes isotopes production.

[f]TBD = to be determined. (ANS construction costs are not yet determined.)

Table A.2. Laboratory personnel summary

	Fiscal year							
	1989	1990	1991	1992	1993	1994	1995	1996
DOE	1449	1415	1641	1825	1621	1636	1655	1614
Work for Others[a]	401[b]	331	377	389	344	347	339	337
Total technical direct	1850	1746	2018	2214	1965	1983	1994	1951
Other direct	234	205	269	301	250	225	220	218
Total direct personnel	2084	1951	2287	2515	2215	2208	2214	2169
Indirect personnel	2599	2576	2650	2650	2650	2650	2650	2650
Total Laboratory	4683	4527	4937	5165	4865	4858	4864	4819

[a]Includes Nuclear Regulatory Commission.

[b]Includes isotope production staff, which is funded out of Program ST beginning in FY 1990.

Table A.3. Funding by assistant secretarial level office
($ in millions—BA)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
Office of Energy Research[b,c]								
Total operating	159.5	155.5	271.1	294.8	187.0	192.6	197.6	201.2
Capital equipment[c]	13.1	14.6	15.4	24.9	27.6	26.3	25.1	23.7
Funded/budgeted construction[c]	27.0	24.4	20.7	9.9	34.6	10.0	10.0	10.0
Total[c]	199.6	194.5	307.2	329.6	249.2	228.9	232.7	234.9
Assistant Secretary for Nuclear Energy								
Total operating	35.9	60.1	59.9	68.4	74.5	58.2	56.1	53.1
Capital equipment	2.0	1.5	3.4	3.1	0.7	0.7	0.7	0.7
Total	37.9	61.6	63.3	71.5	75.2	58.9	56.8	53.8
Office of New Production Reactors								
Total operating		10.2	3.3	5.7	5.7	5.7	5.7	0
Capital equipment		0	2.2	1.7	1.1	1.1	1.1	0
Construction		6.7	10.3	0	0	0	0	0
Total		16.9	15.8	7.4	6.8	6.8	6.8	0
Office of Civilian Radioactive Waste Management								
Total operating	10.3	7.1	11.3	14.3	15.9	17.3	18.5	19.9
Capital equipment	0	0	0.1	*d*	*d*	*d*	0.1	*d*
Total	10.3	7.1	11.4	14.3	15.9	17.3	18.6	19.9
Assistant Secretary for Defense Programs[c]								
Total operating	36.8	38.1	42.2	49.4	49.2	49.5	51.2	52.2
Capital equipment	1.3	1.2	6.7	8.7	5.5	4.8	5.7	3.3
Funded/budgeted construction	2.8	2.7	1.9	6.1	5.6	5.0	5.0	5.0
Total[c]	40.9	42.0	50.8	64.2	60.3	59.3	61.9	60.5
Assistant Secretary for Conservation and Renewable Energy								
Total operating	45.7	47.0	57.8	66.6	67.3	66.4	66.4	66.3
Capital equipment	1.1	2.3	3.8	3.9	3.1	3.1	3.1	3.1
Total	46.8	49.3	61.6	70.5	70.4	69.5	69.5	69.4
Assistant Secretary for Fossil Energy								
Total operating	7.6	6.3	6.8	11.0	11.1	11.6	11.6	11.6
Capital equipment	0	0	0	0.2	0.2	0.2	0.2	0.2
Total	7.6	6.3	6.8	11.2	11.3	11.8	11.8	11.8

Table A.3 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
Assistant Secretary for Environment, Safety, and Health								
Total operating	7.9	4.6	4.2	4.4	4.6	4.8	5.0	5.3
Capital equipment	*d*	0	0	0	0	0	0	0
Total	7.9	4.6	4.2	4.4	4.6	4.8	5.0	5.3
Energy Information Administration								
Total operating	1.6	1.0	1.3	1.6	1.5	1.5	1.5	1.5
Assistant Secretary for Management and Administration								
Total operating	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Funded/budgeted construction[c]	0.2	0.8	0	0	0	0	0	0
Total[c]	0.3	0.9	0.1	0.2	0.2	0.2	0.2	0.2
Office of Policy, Planning, and Analysis								
Total operating	0.4	1.2	1.6	1.6	1.6	1.5	1.5	1.5
Federal Energy Regulatory Commission								
Total operating	0	0	0.4	0.5	0.5	0.5	0.5	0.5
Assistant Secretary for International Affairs and Energy Emergencies								
Total operating	0.2	0.1	0.2	0.3	0.3	0.3	0.3	0.3
Subtotal DOE Programs[b,c]								
Total operating	306.0	331.3	460.2	518.8	419.4	410.1	416.1	413.6
Capital equipment[c]	17.5	19.6	31.6	42.5	38.2	36.2	36.0	31.0
Funded/budgeted construction[c]	30.0	34.6	32.9	16.0	40.2	15.0	15.0	15.0
Total[c]	353.5	385.5	524.7	577.3	497.8	461.3	467.1	459.6
DOE Contractors and Operations Offices								
Total operating	31.7	32.9	25.4	26.5	27.5	27.9	28.4	28.9
Capital equipment	0	0	0.1	0.1	0.1	0.1	0.1	0.1
Total	31.7	32.9	25.5	26.6	27.6	28.0	28.5	29.0
Total DOE Programs[b,c]								
Total operating	337.7	364.2	485.6	545.3	446.9	438.0	444.5	442.5
Capital equipment[c]	17.5	19.6	31.7	42.6	38.3	36.3	36.1	31.1
Funded/budgeted construction[c]	30.0	34.6	32.9	16.0	40.2	15.0	15.0	15.0
Total DOE Programs[c]	385.2	418.4	550.2	603.9	525.4	489.3	495.6	488.6

Table A.3 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
Work for Others								
Nuclear Regulatory Commission								
Total operating	15.9	17.2	17.7	18.3	17.1	17.1	17.1	17.1
Department of Defense								
Total operating	42.4	49.8	72.3	74.8	57.1	57.0	57.0	57.0
Capital equipment	0	0	1.4	1.4	1.3	1.3	1.3	1.3
Total	42.4	49.8	73.7	76.2	58.4	58.3	58.3	58.3
Other federal agencies								
Total operating	16.7	18.5	26.9	22.5	22.0	23.7	23.3	24.0
Other Work for Others								
Total operating	17.2[e]	5.9	6.0	6.0	4.5	5.3	5.5	5.6
Total Work for Others								
Total operating	92.2[e]	91.4	122.9	121.6	100.7	103.1	102.9	103.7
Capital equipment	0	0	1.4	1.4	1.3	1.3	1.3	1.3
Total Work-for-Others programs	92.2[e]	91.4	124.3	123.0	102.0	104.4	104.2	105.0
Total Laboratory[b]								
Total operating	429.9	455.6	608.5	666.9	547.6	541.1	547.4	546.2
Capital equipment	14.1	16.2	29.3	32.6	28.1	26.1	25.9	20.9
Funded/budgeted construction	12.5	20.2	18.2					
General Purpose Equipment	3.4	3.4	3.8	11.4	11.5	11.5	11.5	11.5
General Plant Projects	12.1	10.5	8.2	16.0	40.2	15.0	15.0	15.0
General Purpose Facilities	5.4	3.9	6.5					
Total	477.4	509.8	674.5	726.9	627.4	593.7	599.8	593.6
Proposed construction			2.8	108.2	205.1	TBD[f]	TBD[f]	TBD[f]
Total projected funding	477.4	509.8	677.3	835.1	832.5	TBD[f]	TBD[f]	TBD[f]

[a]Escalation factors from FY 1990 to FY 1991 and from FY 1991 to FY 1992 are both 4.5%. Figures for FY 1993 through FY 1996 are in constant FY 1992 dollars. Applied Technology Division included beginning in FY 1990.

[b]FY 1991 and 1992 data include two FWPs included in the 1991 budget submission to fund OSHA and other safety and health compliance needs.

[c]Includes GPP and/or GPE funding.

[d]Less than $0.1 million.

[e]Includes isotopes production.

[f]To be determined. ANS construction costs are not yet determined.

Table A.4. Personnel by assistant secretarial level office
[Full-time equivalents (FTEs)]

	Fiscal year							
	1989	1990	1991	1992	1993	1994	1995	1996
Office of Energy Research								
Technical personnel	820.1	703.4	915.1[a]	1027.7[a]	786.6	800.7	809.6	821.7
Other direct personnel	115.9	86.4	139.3[a]	162.3[a]	93.9	79.8	78.4	76.9
Total direct personnel	936.0	789.8	1054.4[a]	1190.0[a]	880.5	880.5	888.0	898.6
Assistant Secretary for Nuclear Energy								
Technical personnel	167.8	206.0	221.6	200.5	191.7	171.6	168.4	163.4
Other direct personnel	23.6	30.2	44.7	51.7	68.0	52.8	47.6	47.2
Total direct personnel	191.4	236.2	266.3	252.2	259.7	224.4	216.0	210.6
Office of New Production Reactors								
Technical personnel		59.2	61.5	64.7	64.5	64.5	65.5	0
Other direct personnel		1.7	0.9	1.1	1.0	1.0	0	0
Total direct personnel		60.9	62.4	65.8	65.5	65.5	65.5	0
Office of Civilian Radioactive Waste Management								
Technical personnel	25.4	14.3	22.9	25.2	27.9	30.7	33.4	35.9
Other direct personnel	8.7	2.0	5.6	6.1	6.3	6.6	7.0	7.2
Total direct personnel	34.1	16.3	28.5	31.3	34.2	37.3	40.4	43.1
Assistant Secretary for Defense Programs								
Technical personnel	126.2	108.2	118.8	155.6	199.6	219.6	229.6	244.6
Other direct personnel	27.1	18.5	32.0	32.1	37.1	40.1	42.1	42.1
Total direct personnel	153.3	126.7	150.8	187.7	236.7	259.7	271.7	286.7
Assistant Secretary for Conservation and Renewable Energy								
Technical personnel	134.6	136.9	139.1	175.8	175.8	173.8	173.3	173.3
Other direct personnel	2.2	1.4	4.9	3.8	4.3	6.3	6.3	6.3
Total direct personnel	136.8	138.3	144.0	179.6	180.1	180.1	179.6	179.6
Assistant Secretary for Fossil Energy								
Technical personnel	25.8	20.6	21.3	26.5	25.8	27.3	27.7	27.7
Other direct personnel	0.5	0.1	0	0	0	0	0	0
Total direct personnel	26.3	20.7	21.3	26.5	25.8	27.3	27.7	27.7
Assistant Secretary for Environment, Safety, and Health								
Technical personnel	27.8	15.1	12.8	15.0	15.0	15.0	15.0	15.0
Other direct personnel	5.2	4.2	4.0	4.0	4.0	4.0	4.0	4.0
Total direct personnel	33.0	19.3	16.8	19.0	19.0	19.0	19.0	19.0

Table A.4 (continued)

	Fiscal year							
	1989	1990	1991	1992	1993	1994	1995	1996
Energy Information Administration								
Technical personnel	2.4	2.1	1.3	3.2	3.0	3.0	3.0	3.0
Other direct personnel	0.2	0.1	1.0	0	0	0	0	0
Total direct personnel	2.6	2.2	2.3	3.2	3.0	3.0	3.0	3.0
Assistant Secretary for Management and Administration								
Technical personnel	0	0	0	0	0	0	0	0
Other direct personnel	0.1	0.8	1.2	1.0	1.0	1.0	1.0	1.0
Total direct personnel	0.1	0.8	1.2	1.0	1.0	1.0	1.0	1.0
Office of Policy, Planning, and Analysis								
Technical personnel	0.9	2.5	5.1	4.0	4.0	3.0	3.0	3.0
Other direct personnel	0	0	0	1.0	1.0	0	0	0
Total direct personnel	0.9	2.5	5.1	5.0	5.0	3.0	3.0	3.0
Federal Energy Regulatory Commission								
Technical personnel	0.6	0.3	1.6	2.6	2.6	2.6	2.6	2.6
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0.6	0.3	1.6	2.6	2.6	2.6	2.6	2.6
Assistant Secretary for International Affairs and Energy Emergencies								
Technical personnel	0	0.4	0.5	0.9	0.9	0.9	0.9	0.9
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0	0.4	0.5	0.9	0.9	0.9	0.9	0.9
Subtotal DOE Programs[b]								
Technical personnel	1331.6	1269.0	1521.6	1701.7	1497.4	1512.7	1532.0	1491.1
Other direct personnel	183.5	145.4	233.6	263.1	216.6	191.6	186.4	184.7
Total direct personnel	1515.1	1414.4	1755.2	1964.8	1714.0	1704.3	1718.4	1675.8
DOE Contractors and Operations Offices								
Technical personnel	117.1	146.0	119.0	123.6	123.5	123.4	123.1	123.1
Other direct personnel	12.3	23.8	8.9	7.8	7.8	7.8	7.8	7.8
Total direct personnel	129.4	169.8	127.9	131.4	131.3	131.2	130.9	130.9
Total DOE Programs[b]								
Technical personnel	1448.7	1415.0	1640.6	1825.3	1620.9	1636.1	1655.1	1614.2
Other direct personnel	195.8	169.2	242.5	270.9	224.4	199.4	194.2	192.5
Total direct personnel	1644.5	1584.2	1883.1	2096.2	1845.3	1835.5	1849.3	1806.7

Table A.4 (continued)

	Fiscal year							
	1989	1990	1991	1992	1993	1994	1995	1996
Work for Others								
Nuclear Regulatory Commission								
Technical personnel	53.8	55.5	66.6	66.5	59.6	59.6	59.6	59.6
Other direct personnel	12.3	11.7	7.5	12.7	11.2	11.2	11.2	11.2
Total direct personnel	66.1	67.2	74.1	79.2	70.8	70.8	70.8	70.8
Department of Defense								
Technical personnel	166.5	165.4	178.3	200.0	170.3	170.3	170.3	170.3
Other direct personnel	16.9	17.6	9.7	10.0	7.9	7.9	7.9	7.9
Total direct personnel	183.4	183.0	188.0	210.0	178.2	178.2	178.2	178.2
Other Federal Agencies								
Technical personnel	104.2	88.8	106.5	102.6	94.7	98.2	90.0	87.8
Other direct personnel	4.9	5.3	6.2	5.0	4.5	4.5	4.5	4.5
Total direct personnel	109.1	94.1	112.7	107.6	99.2	102.7	94.5	92.3
Other Work for Others[b]								
Technical personnel	76.8	21.5	26.1	19.5	19.3	18.5	19.4	19.3
Other direct personnel	4.5	1.3	2.6	2.3	2.3	2.3	2.3	2.3
Total direct personnel	81.3	22.8	28.7	21.8	21.6	20.8	21.7	21.6
Total Work for Others[b]								
Technical personnel	401.3	331.2	377.5	388.6	343.9	346.6	339.3	337.0
Other direct personnel	38.6	35.9	26.0	30.0	25.9	25.9	25.9	25.9
Total direct personnel	439.9	367.1	403.5	418.6	369.8	372.5	365.2	362.9
Total Laboratory[b]								
Technical personnel[a]	1850	1746	2018	2214	1965	1983	1994	1951
Other direct personnel	234	205	269	301	250	225	220	218
Total direct personnel	2084	1951	2287	2515	2215	2208	2214	2169
Total indirect personnel	2599	2576	2650	2650	2650	2650	2650	2650
Total Laboratory personnel	4683	4527	4937	5165	4865	4858	4864	4819

[a]Includes two FWPs included in FY 1991 budget submission to fund OSHA and other safety and health compliance needs.
[b]Isotopes production for FY 1989 included under "Other Work for Others."

Table A.5. Resources by program
($ in millions—BA)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
Office of Energy Research								
AT—Magnetic Fusion								
Total operating	37.3	28.4	28.2	28.5	28.5	28.5	28.5	28.5
Capital equipment	1.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Total program	39.1	29.9	29.7	30.0	30.0	30.0	30.0	30.0
Technical personnel	125.3	105.0	97.4	98.0	98.0	98.0	98.0	98.0
Other direct personnel	71.7	53.1	48.7	49.0	49.0	49.0	49.0	49.0
Total direct personnel	197.0	158.1	146.1	147.0	147.0	147.0	147.0	147.0
AT—Landlord (includes GPP and GPE)[b]								
Total operating	0	0	115.5	113.6	0	0	0	0
GPE capital equipment	3.1	3.0	3.1	9.3	9.0	9.0	9.0	9.0
GPP construction	6.6	6.0	4.3	7.8	26.7	8.0	8.0	8.0
Total program	9.7	9.0	122.9	130.7	35.7	17.0	17.0	17.0
Technical personnel	0	0	215.7	247.3	0	0	0	0
Other direct personnel	0	0	53.5	73.5	0	0	0	0
Total direct personnel	0	0	269.2	320.8	0	0	0	0
KA—High Energy Physics								
Total operating	0.8	0.4	0.4	1.1	1.5	1.7	2.0	2.3
Capital equipment	c	0	0	0	0.1	0.1	0.1	0.1
Total program	0.8	0.4	0.4	1.1	1.6	1.8	2.1	2.4
Technical personnel	3.5	1.9	2.9	5.3	7.3	8.3	9.3	10.3
Other direct personnel	0.4	0.6	0.6	0.5	0.5	0.5	1.0	1.5
Total direct personnel	3.9	2.5	3.5	5.8	7.8	8.8	10.3	11.8
KB—Nuclear Physics								
Total operating	13.7	13.4	13.4	15.9	16.0	16.2	16.3	16.4
Capital equipment	1.1	1.7	1.4	2.1	2.1	2.1	2.2	2.2
Construction	0	0.2	0	0	0	0	0	0
Total program	14.8	15.3	14.8	18.0	18.1	18.3	18.5	18.6
Proposed construction	0	0	0	1.2	0	0	0	0
Technical personnel	88.8	75.1	68.0	78.6	78.6	78.6	78.6	78.6
Other direct personnel	0.9	2.0	1.5	1.3	1.3	1.3	1.3	1.3
Total direct personnel	89.7	77.1	69.5	79.9	79.9	79.9	79.9	79.9

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
KC—Basic Energy Sciences								
Total operating	71.5	69.4	71.8	87.2	91.1	94.2	95.8	96.4
Capital equipment	5.6	6.6	7.5	8.7	11.1	9.7	8.3	6.8
Construction	0.7	1.3	0	0	0	0	0	0
Total program	77.8	77.3	79.3	95.9	102.2	103.9	104.1	103.2
Proposed construction[d]	0	0	2.8	48.0	60.5	TBD	TBD	TBD
Technical personnel	421.4	346.4	360.0	396.1	403.8	414.9	421.8	432.9
Other direct personnel	30.6	24.6	20.0	20.4	26.6	13.5	11.6	10.6
Total direct personnel	452.0	371.0	380.0	416.5	430.4	428.4	433.4	443.5
KD—Energy Research Analyses								
Total operating	1.5	2.1	1.0	1.5	1.5	1.5	1.5	1.5
Technical personnel	4.5	4.8	3.5	4.4	4.4	4.4	4.4	4.4
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	4.5	4.8	3.5	4.4	4.4	4.4	4.4	4.4
KE/KT—University and Science Education								
Total operating	0.8	0.8	0.4	0.6	0.8	1.0	1.5	2.0
Technical personnel	2.3	4.1	3.5	4.0	4.5	6.0	7.0	8.0
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	2.3	4.1	3.5	4.0	4.5	6.0	7.0	8.0
KG (EX)—Multiprogram Energy Laboratories Facilities Support[e]								
Total operating	8.8	14.0	14.3	18.2	17.8	18.2	19.1	19.5
Capital equipment[f]	0.3	0.4	0.7	2.1	2.5	2.5	2.5	2.5
Construction[f]	19.7	16.9	16.4	2.1	7.9	2.0	2.0	2.0
Total program	28.8	31.3	31.4	22.4	28.2	22.7	23.6	24.0
Proposed construction	0	0	0	45.8	91.9	133.1	154.9	121.5
Technical personnel	51.7	52.0	51.8	75.0	70.0	70.0	69.5	68.5
Other direct personnel	6.8	3.0	10.0	12.6	11.5	10.5	10.5	9.5
Total direct personnel	58.5	55.0	61.8	87.6	81.5	80.5	80.0	78.0
KP—Environmental Research and Development								
Total operating	25.1	26.5	25.9	28.0	29.4	30.8	32.3	34.0
Capital equipment	1.2	1.2	1.2	1.2	1.3	1.3	1.4	1.5
Total program	26.3	27.7	27.1	29.2	30.7	32.1	33.7	35.5
Proposed construction	0	0	0	0.6	7.5	23.5	32.2	3.9
Technical personnel	122.6	112.5	111.7	118.0	118.0	118.0	118.0	118.0
Other direct personnel	5.5	3.1	5.0	5.0	5.0	5.0	5.0	5.0
Total direct personnel	128.1	115.6	116.7	123.0	123.0	123.0	123.0	123.0

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
KS—Superconducting Super Collider								
Total operating		0.5	0.2	0.2	0.4	0.5	0.6	0.6
Capital equipment		0.2	0	0	0	0.1	0.1	0.1
Total program		0.7	0.2	0.2	0.4	0.6	0.7	0.7
Technical personnel		1.6	0.6	1.0	2.0	2.5	3.0	3.0
Other direct personnel		0	0	0	0	0	0	0
Total direct personnel		1.6	0.6	1.0	2.0	2.5	3.0	3.0
Office of Energy Research[b,d]								
Total operating	159.5	155.5	271.1	294.8	187.0	192.6	197.6	201.2
Capital equipment	13.1	14.6	15.4	24.9	27.6	26.3	25.1	23.7
Construction	27.0	24.4	20.7	9.9	34.6	10.0	10.0	10.0
Total	199.6	194.5	307.2	329.6	249.2	228.9	232.7	234.9
Proposed construction	0	0	2.8	95.6	159.9	TBD	TBD	TBD
Technical personnel	820.1	703.4	915.1	1027.7	786.6	800.7	809.6	821.7
Other direct personnel	115.9	86.4	139.3	162.3	93.9	79.8	78.4	76.9
Total direct personnel	936.0	789.8	1054.4	1190.0	880.5	880.5	888.0	898.6
Assistant Secretary for Nuclear Energy								
AF—Nuclear Energy Research Development								
Total operating	30.5	31.5	39.7	49.5	56.2	40.7	40.9	40.3
Capital equipment	1.9	1.3	3.4	3.1	0.7	0.7	0.7	0.7
Total program	32.4	32.8	43.1	52.6	56.9	41.4	41.6	41.0
Technical personnel	142.5	127.5	152.3	138.5	135.6	116.9	117.0	115.0
Other direct personnel	23.2	15.1	22.8	26.2	42.5	27.3	26.1	25.7
Total direct personnel	165.7	142.6	175.1	164.7	178.1	144.2	143.1	140.7
AH—Remedial Action and Waste Technology								
Total operating	4.9	5.4	3.3	1.9	1.8	1.5	1.3	1.3
Capital equipment	0.1	0.1	0	c	0	0	0	0
Total program	5.0	5.5	3.3	1.9	1.8	1.5	1.3	1.3
Technical personnel	23.0	14.0	15.1	10.4	9.5	8.1	6.8	6.8
Other direct personnel	0.4	0	0	0	0	0	0	0
Total direct personnel	23.4	14.0	15.1	10.4	9.5	8.1	6.8	6.8
AJ—Naval Reactors								
Total operating	c	c	c	0.1	0.1	0.1	0.1	0.1
Technical personnel	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
CD—Uranium Enrichment[g]								
Total operating	0.5	8.5	8.9	9.4	8.9	8.4	6.3	3.9
Technical personnel	2.0	15.2	16.8	17.8	12.8	12.8	10.8	7.8
Other direct personnel	0	12.0	9.0	9.0	9.0	9.0	5.0	5.0
Total direct personnel	2.0	27.2	25.8	26.8	21.8	21.8	15.8	12.8
ST—Isotope Production and Distribution Program[h]								
Total operating		14.7	8.0	7.5	7.5	7.5	7.5	7.5
Capital equipment		0.1	0	0	0	0	0	0
Total program		14.8	8.0	7.5	7.5	7.5	7.5	7.5
Technical personnel		49.0	37.1	33.5	33.5	33.5	33.5	33.5
Other direct personnel		3.1	12.9	16.5	16.5	16.5	16.5	16.5
Total direct personnel		52.1	50.0	50.0	50.0	50.0	50.0	50.0
Total Assistant Secretary for Nuclear Energy								
Total operating	35.9	60.1	59.9	68.4	74.5	58.2	56.1	53.1
Capital equipment	2.0	1.5	3.4	3.1	0.7	0.7	0.7	0.7
Total	37.9	61.6	63.3	71.5	75.2	58.9	56.8	53.8
Technical personnel	167.8	206.0	221.6	200.5	191.7	171.6	168.4	163.4
Other direct personnel	23.6	30.2	44.7	51.7	68.0	52.8	47.6	47.2
Total direct personnel	191.4	236.2	266.3	252.2	259.7	224.4	216.0	210.6
Office of New Production Reactors								
NP—New Production Reactors								
Total operating		10.2	3.3	5.7	5.7	5.7	5.7	0
Capital equipment		0	2.2	1.7	1.1	1.1	1.1	0
Construction		6.7	10.3	0	0	0	0	0
Total program		16.9	15.8	7.4	6.8	6.8	6.8	0
Proposed construction		0	0	12.6	13.2	13.2	13.2	0
Technical personnel		59.2	61.5	64.7	64.5	64.5	65.5	0
Other direct personnel		1.7	0.9	1.1	1.0	1.0	0	0
Total direct personnel		60.9	62.4	65.8	65.5	65.5	65.5	0
Total Office of New Production Reactors								
Total operating		10.2	3.3	5.7	5.7	5.7	5.7	0
Capital equipment		0	2.2	1.7	1.1	1.1	1.1	0
Construction		6.7	10.3	0	0	0	0	0
Total program		16.9	15.8	7.4	6.8	6.8	6.8	0
Proposed construction		0	0	12.6	13.2	13.2	13.2	0
Technical personnel		59.2	61.5	64.7	64.5	64.5	65.5	0
Other direct personnel		1.7	0.9	1.1	1.0	1.0	0	0
Total direct personnel		60.9	62.4	65.8	65.5	65.5	65.5	0

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
Office of Civilian Radioactive Waste Management								
DB—Nuclear Waste Fund								
Total operating	10.3	7.1	11.3	14.3	15.9	17.3	18.5	19.9
Capital equipment	0	0	0.1	c	c	c	0.1	c
Total program	10.3	7.1	11.4	14.3	15.9	17.3	18.6	19.9
Technical personnel	25.4	14.3	22.9	25.2	27.9	30.7	33.4	35.9
Other direct personnel	8.7	2.0	5.6	6.1	6.3	6.6	7.0	7.2
Total direct personnel	34.1	16.3	28.5	31.3	34.2	37.3	40.4	43.1
Total Office of Civilian Radioactive Waste Management								
Total operating	10.3	7.1	11.3	14.3	15.9	17.3	18.5	19.9
Capital equipment	0	0	0.1	c	c	c	0.1	c
Total	10.3	7.1	11.4	14.3	15.9	17.3	18.6	19.9
Technical personnel	25.4	14.3	22.9	25.2	27.9	30.7	33.4	35.9
Other direct personnel	8.7	2.0	5.6	6.1	6.3	6.6	7.0	7.2
Total direct personnel	34.1	16.3	28.5	31.3	34.2	37.3	40.4	43.1
Assistant Secretary for Defense Programs								
GB—Weapons Activities								
Total operating	1.7	1.9	0.7	0.3	0.3	0.3	0.3	0.3
Technical personnel	13.2	9.9	3.9	1.5	1.5	1.5	1.5	1.5
Other direct personnel	2.4	0.5	0.5	0.6	0.6	0.6	0.6	0.6
Total direct personnel	15.6	10.4	4.4	2.1	2.1	2.1	2.1	2.1
GD—Nuclear Safeguards and Security								
Total operating	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.7
Capital equipment	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.1
Total program	0.7	0.7	0.7	0.7	0.8	0.8	0.9	0.8
Technical personnel	3.8	3.3	3.1	3.4	3.4	3.4	3.4	3.4
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	3.8	3.3	3.1	3.4	3.4	3.4	3.4	3.4
GE—Materials Production								
Total operating	7.5	5.3	6.1	7.4	7.9	7.9	7.9	7.9
Capital equipment	0.2	0.2	0	1.7	0.3	0.3	1.8	0.3
Total program	7.7	5.5	6.1	9.1	8.2	8.2	9.7	8.2
Technical personnel	40.7	29.2	21.8	30.7	39.7	39.7	39.7	39.7
Other direct personnel	2.6	1.7	6.5	1.5	1.5	1.5	1.5	1.5
Total direct personnel	43.3	30.9	28.3	32.2	41.2	41.2	41.2	41.2

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
GF/EW—Defense Environmental Restoration and Waste Management								
Total operating	27.1	30.4	34.9	41.1	40.4	40.6	42.3	43.3
Capital equipment	0.9	0.8	6.5	6.9	5.0	4.4	3.7	2.9
Construction[i]	2.8	2.7	1.9	6.1	5.6	5.0	5.0	5.0
Total program	30.8	33.9	43.3	54.1	51.0	50.0	51.0	51.2
Proposed construction	0	0	0	0	32.0	70.5	129.5	43.0
Technical personnel	68.5	65.8	90.0	120.0	155.0	175.0	185.0	200.0
Other direct personnel	22.1	16.3	25.0	30.0	35.0	38.0	40.0	40.0
Total direct personnel	90.6	82.1	115.0	150.0	190.0	213.0	225.0	240.0
Total Assistant Secretary for Defense Programs								
Total operating	36.8	38.1	42.2	49.4	49.2	49.5	51.2	52.2
Capital equipment	1.3	1.2	6.7	8.7	5.5	4.8	5.7	3.3
Construction	2.8	2.7	1.9	6.1	5.6	5.0	5.0	5.0
Total	40.9	42.0	50.8	64.2	60.3	59.3	61.9	60.5
Proposed construction	0	0	0	0	32.0	70.5	129.5	43.0
Technical personnel	126.2	108.2	118.8	155.6	199.6	219.6	229.6	244.6
Other direct personnel	27.1	18.5	32.0	32.1	37.1	40.1	42.1	42.1
Total direct personnel	153.3	126.7	150.8	187.7	236.7	259.7	271.7	286.7
Assistant Secretary for Conservation and Renewable Energy								
AK—Electric Energy Systems								
Total operating	4.6	4.4	9.8	10.3	10.3	10.3	10.3	10.3
Capital equipment	0	0	0.2	0.2	0.2	0.2	0.2	0.2
Total program	4.6	4.4	10.0	10.5	10.5	10.5	10.5	10.5
Technical personnel	15.1	16.6	25.3	27.7	28.0	28.0	28.0	28.0
Other direct personnel	0	0	0	0	0	2.0	2.0	2.0
Total direct personnel	15.1	16.6	25.3	27.7	28.0	30.0	30.0	30.0
AL—Energy Storage Systems								
Total operating	1.0	0.4	1.6	1.7	1.7	1.7	1.7	1.7
Technical personnel	2.7	1.7	3.1	3.2	3.2	3.2	3.2	3.2
Other direct personnel	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel	2.7	1.8	3.2	3.3	3.3	3.3	3.3	3.3
CE—Hydropower								
Total operating	c	0.2	0.6	0.4	0.4	0.4	0.4	0.4
Technical personnel	0	0.4	2.9	1.5	1.5	1.5	1.5	1.5
Other direct personnel	0	0.1	0	0	0	0	0	0
Total direct personnel	0	0.5	2.9	1.5	1.5	1.5	1.5	1.5

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
EB—Solar Energy								
Total operating	2.8	3.3	5.1	8.7	8.6	8.6	8.6	8.6
Capital equipment	0.1	0.2	0.1	0.4	0.2	0.2	0.2	0.2
Total program	2.9	3.5	5.2	9.1	8.8	8.8	8.8	8.8
Technical personnel	8.4	7.8	9.6	12.3	11.8	11.8	11.8	11.8
Other direct personnel	0	0	0.1	0.5	0.5	0.5	0.5	0.5
Total direct personnel	8.4	7.8	9.7	12.8	12.3	12.3	12.3	12.3
EC—Buildings and Community Systems								
Total operating	9.9	9.3	10.5	12.7	12.7	12.7	12.7	12.7
Capital equipment	0.3	0.2	0.4	0.5	0.2	0.2	0.2	0.2
Total program	10.2	9.5	10.9	13.2	12.9	12.9	12.9	12.9
Technical personnel	33.1	32.7	26.1	37.9	37.1	37.1	37.1	37.1
Other direct personnel	1.2	0	0.7	0.5	0.5	0.5	0.5	0.5
Total direct personnel	34.3	32.7	26.8	38.4	37.6	37.6	37.6	37.6
ED—Industrial Energy Conservation								
Total operating	2.3	2.0	2.5	3.1	3.5	3.5	3.5	3.5
Capital equipment	0	0	c	c	0.2	0.2	0.2	0.2
Total program	2.3	2.0	2.5	3.1	3.7	3.7	3.7	3.7
Technical personnel	10.2	11.0	9.3	12.0	12.5	12.5	12.5	12.5
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	10.2	11.0	9.3	12.0	12.5	12.5	12.5	12.5
EE—Transportation								
Total operating	19.6	20.0	21.0	21.4	21.6	21.5	21.5	21.5
Capital equipment	0.6	1.4	2.1	1.8	1.3	1.3	1.3	1.3
Total program	20.2	21.4	23.1	23.2	22.9	22.8	22.8	22.8
Technical personnel	46.5	44.4	38.7	48.8	48.8	48.8	48.8	48.8
Other direct personnel	1.0	0.6	0.7	0.2	0.2	0.2	0.2	0.2
Total direct personnel	47.5	45.0	39.4	49.0	49.0	49.0	49.0	49.0
EF—State/Local Programs								
Total operating	0.2	1.8	2.0	1.9	2.1	1.3	1.3	1.2
Technical personnel	1.6	3.7	8.0	7.8	8.3	6.3	5.8	5.8
Other direct personnel	0	0	2.3	2.5	3.0	3.0	3.0	3.0
Total direct personnel	1.6	3.7	10.3	10.3	11.3	9.3	8.8	8.8

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
EG—Multisector								
Total operating	5.3	5.6	4.7	6.4	6.4	6.4	6.4	6.4
Capital equipment	0.1	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Total program	5.4	6.1	5.7	7.4	7.4	7.4	7.4	7.4
Technical personnel	17.0	18.6	16.1	24.6	24.6	24.6	24.6	24.6
Other direct personnel	0	0.7	1.0	0	0	0	0	0
Total direct personnel	17.0	19.3	17.1	24.6	24.6	24.6	24.6	24.6
Total Assistant Secretary for Conservation and Renewable Energy								
Total operating	45.7	47.0	57.8	66.6	67.3	66.4	66.4	66.3
Capital equipment	1.1	2.3	3.8	3.9	3.1	3.1	3.1	3.1
Total	46.8	49.3	61.6	70.5	70.4	69.5	69.5	69.4
Technical personnel	134.6	136.9	139.1	175.8	175.8	173.8	173.3	173.3
Other direct personnel	2.2	1.4	4.9	3.8	4.3	6.3	6.3	6.3
Total direct personnel	136.8	138.3	144.0	179.6	180.1	180.1	179.6	179.6
Assistant Secretary for Fossil Energy								
AA—Coal								
Total operating	5.8	5.6	5.6	9.6	9.6	10.0	10.0	10.0
Capital equipment	0	0	0	0.2	0.2	0.2	0.2	0.2
Total program	5.8	5.6	5.6	9.8	9.8	10.2	10.2	10.2
Technical personnel	22.1	15.7	16.5	19.2	18.2	19.1	19.5	19.5
Other direct personnel	0.5	0.1	0	0	0	0	0	0
Total direct personnel	22.6	15.8	16.5	19.2	18.2	19.1	19.5	19.5
AN—Energy Technology Center Program Direction								
Total operating	0	0	0	0	0	0	0	0
Technical personnel	0.1	0	0	0	0	0	0	0
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0.1	0	0	0	0	0	0	0
AZ—Innovative Clean Coal Technology								
Total operating	1.1	0.5	0.8	1.0	1.1	1.2	1.2	1.2
Technical personnel	2.1	3.0	3.1	5.1	5.4	6.0	6.0	6.0
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	2.1	3.0	3.1	5.1	5.4	6.0	6.0	6.0
CB—Naval Petroleum and Oil Shale Reserves								
Total operating	0	c	0	0	0	0	0	0
Technical personnel	0	0.2	0	0	0	0	0	0
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0	0.2	0	0	0	0	0	0

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
SA—Strategic Petroleum Reserve								
Total operating	0.7	0.2	0.4	0.4	0.4	0.4	0.4	0.4
Technical personnel	1.5	1.7	1.7	2.2	2.2	2.2	2.2	2.2
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	1.5	1.7	1.7	2.2	2.2	2.2	2.2	2.2
Total Assistant Secretary for Fossil Energy								
Total operating	7.6	6.3	6.8	11.0	11.1	11.6	11.6	11.6
Capital equipment	0	0	0	0.2	0.2	0.2	0.2	0.2
Total program	7.6	6.3	6.8	11.2	11.3	11.8	11.8	11.8
Technical personnel	25.8	20.6	21.3	26.5	25.8	27.3	27.7	27.7
Other direct personnel	0.5	0.1	0	0	0	0	0	0
Total direct personnel	26.3	20.7	21.3	26.5	25.8	27.3	27.7	27.7
Assistant Secretary for Environment, Safety, and Health								
HA—Environment, Safety, and Health								
Total operating	7.9	4.6	4.2	4.4	4.6	4.8	5.0	5.3
Capital equipment	*c*	0	0	0	0	0	0	0
Total program	7.9	4.6	4.2	4.4	4.6	4.8	5.0	5.3
Technical personnel	27.8	15.1	12.8	15.0	15.0	15.0	15.0	15.0
Other direct personnel	5.2	4.2	4.0	4.0	4.0	4.0	4.0	4.0
Total direct personnel	33.0	19.3	16.8	19.0	19.0	19.0	19.0	19.0
Total Assistant Secretary for Environment, Safety, and Health								
Total operating	7.9	4.6	4.2	4.4	4.6	4.8	5.0	5.3
Capital equipment	*c*	0	0	0	0	0	0	0
Total	7.9	4.6	4.2	4.4	4.6	4.8	5.0	5.3
Technical personnel	27.8	15.1	12.8	15.0	15.0	15.0	15.0	15.0
Other direct personnel	5.2	4.2	4.0	4.0	4.0	4.0	4.0	4.0
Total direct personnel	33.0	19.3	16.8	19.0	19.0	19.0	19.0	19.0
Energy Information Administration								
TA—Energy Information Administration System								
Total operating	1.6	1.0	1.3	1.6	1.5	1.5	1.5	1.5
Technical personnel	2.4	2.1	1.3	3.2	3.0	3.0	3.0	3.0
Other direct personnel	0.2	0.1	1.0	0	0	0	0	0
Total direct personnel	2.6	2.2	2.3	3.2	3.0	3.0	3.0	3.0

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
Total Energy Information Administration								
Total operating	1.6	1.0	1.3	1.6	1.5	1.5	1.5	1.5
Technical personnel	2.4	2.1	1.3	3.2	3.0	3.0	3.0	3.0
Other direct personnel	0.2	0.1	1.0	0	0	0	0	0
Total direct personnel	2.6	2.2	2.3	3.2	3.0	3.0	3.0	3.0
Assistant Secretary for Management and Administration								
WB—In-House Energy Management								
Total operating	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Construction	0.2	0.8	0	0	0	0	0	0
Total program	0.3	0.9	0.1	0.2	0.2	0.2	0.2	0.2
Technical personnel	0	0	0	0	0	0	0	0
Other direct personnel	0.1	0.8	1.2	1.0	1.0	1.0	1.0	1.0
Total direct personnel	0.1	0.8	1.2	1.0	1.0	1.0	1.0	1.0
Total Assistant Secretary for Management and Administration								
Total operating	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Construction	0.2	0.8	0	0	0	0	0	0
Total program	0.3	0.9	0.1	0.2	0.2	0.2	0.2	0.2
Technical personnel	0	0	0	0	0	0	0	0
Other direct personnel	0.1	0.8	1.2	1.0	1.0	1.0	1.0	1.0
Total direct personnel	0.1	0.8	1.2	1.0	1.0	1.0	1.0	1.0
Office of Policy, Planning, and Analysis								
PE—Policy, Planning, and Analysis								
Total operating	0.4	1.2	1.6	1.6	1.6	1.5	1.5	1.5
Technical personnel	0.9	2.5	5.1	4.0	4.0	3.0	3.0	3.0
Other direct personnel	0	0	0	1.0	1.0	0	0	0
Total direct personnel	0.9	2.5	5.1	5.0	5.0	3.0	3.0	3.0
Total Office of Policy, Planning, and Analysis								
Total operating	0.4	1.2	1.6	1.6	1.6	1.5	1.5	1.5
Technical personnel	0.9	2.5	5.1	4.0	4.0	3.0	3.0	3.0
Other direct personnel	0	0	0	1.0	1.0	0	0	0
Total direct personnel	0.9	2.5	5.1	5.0	5.0	3.0	3.0	3.0

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
Federal Energy Regulatory Commission								
VR—Federal Energy Regulatory Commission								
Total operating	0	0	0.4	0.5	0.5	0.5	0.5	0.5
Technical personnel	0.6	0.3	1.6	2.6	2.6	2.6	2.6	2.6
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0.6	0.3	1.6	2.6	2.6	2.6	2.6	2.6
Total Federal Energy Regulatory Commission								
Total operating	0	0	0.4	0.5	0.5	0.5	0.5	0.5
Technical personnel	0.6	0.3	1.6	2.6	2.6	2.6	2.6	2.6
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0.6	0.3	1.6	2.6	2.6	2.6	2.6	2.6
Assistant Secretary for International Affairs and Energy Emergencies								
NA—International Affairs								
Total operating	0.1	0	c	0.1	0.1	0.1	0.1	0.1
Technical personnel	0	0.3	0.1	0.5	0.5	0.5	0.5	0.5
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0	0.3	0.1	0.5	0.5	0.5	0.5	0.5
NB—Emergency Preparedness								
Total operating	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Technical personnel	0	0.1	0.4	0.4	0.4	0.4	0.4	0.4
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0	0.1	0.4	0.4	0.4	0.4	0.4	0.4
Total Assistant Secretary for International Affairs and Energy Emergencies								
Total operating	0.2	0.1	0.2	0.3	0.3	0.3	0.3	0.3
Technical personnel	0	0.4	0.5	0.9	0.9	0.9	0.9	0.9
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0	0.4	0.5	0.9	0.9	0.9	0.9	0.9
Subtotal DOE Programs								
Total operating	306.0	331.3	460.2	518.8	419.4	410.1	416.1	413.6
Capital equipment	17.5	19.6	31.6	42.5	38.2	36.2	36.0	31.0
Construction	30.0	34.6	32.9	16.0	40.2	15.0	15.0	15.0
Total	353.5	385.5	524.7	577.3	497.8	461.3	467.1	459.6
Proposed construction	0	0	2.8	108.2	205.1	TBD	TBD	TBD
Technical personnel	1331.6	1269.0	1521.6	1701.7	1497.4	1512.7	1532.0	1491.1
Other direct personnel	183.5	145.4	233.6	263.1	216.6	191.6	186.4	184.7
Total direct personnel	1515.1	1414.4	1755.2	1964.8	1714.0	1704.3	1718.4	1675.8

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
DOE Contractors and Operations Office								
Total operating	31.7	32.9	25.4	26.5	27.5	27.9	28.4	28.9
Capital equipment	0	0	0.1	0.1	0.1	0.1	0.1	0.1
Total program	31.7	32.9	25.5	26.6	27.6	28.0	28.5	29.0
Technical personnel	117.1	146.0	119.0	123.6	123.5	123.4	123.1	123.1
Other direct personnel	12.3	23.8	8.9	7.8	7.8	7.8	7.8	7.8
Total direct personnel	129.4	169.8	127.9	131.4	131.3	131.2	130.9	130.9
Total DOE Programs								
Total operating	337.7	364.2	485.6	545.3	446.9	438.0	444.5	442.5
Capital equipment	17.5	19.6	31.7	42.6	38.3	36.3	36.1	31.1
Construction	30.0	34.6	32.9	16.0	40.2	15.0	15.0	15.0
Total program	385.2	418.4	550.2	603.9	525.4	489.3	495.6	488.6
Proposed construction	0	0	2.8	108.2	205.1	TBD	TBD	TBD
Technical personnel	1448.7	1415.0	1640.6	1825.3	1620.9	1636.1	1655.1	1614.2
Other direct personnel	195.8	169.2	242.5	270.9	224.4	199.4	194.2	192.5
Total direct personnel	1644.5	1584.2	1883.1	2096.2	1845.3	1835.5	1849.3	1806.7
Work for Others								
Nuclear Regulatory Commission								
Total operating	15.9	17.2	17.7	18.3	17.1	17.1	17.1	17.1
Technical personnel	53.8	55.5	66.6	66.5	59.6	59.6	59.6	59.6
Other direct personnel	12.3	11.7	7.5	12.7	11.2	11.2	11.2	11.2
Total direct personnel	66.1	67.2	74.1	79.2	70.8	70.8	70.8	70.8
Department of Defense								
Total operating	42.4	49.8	72.3	74.8	57.1	57.0	57.0	57.0
Capital equipment	0	0	1.4	1.4	1.3	1.3	1.3	1.3
Total program	42.4	49.8	73.7	76.2	58.4	58.3	58.3	58.3
Technical personnel	166.5	165.4	178.3	200.0	170.3	170.3	170.3	170.3
Other direct personnel	16.9	17.6	9.7	10.0	7.9	7.9	7.9	7.9
Total direct personnel	183.4	183.0	188.0	210.0	178.2	178.2	178.2	178.2
National Aeronautics and Space Administration								
Total operating	2.0	2.1	3.2	3.5	3.1	4.1	3.1	3.1
Technical personnel	15.0	5.9	15.4	17.0	13.5	13.5	13.5	13.5
Other direct personnel	0.5	0.4	0.9	0.8	0.8	0.8	0.8	0.8
Total direct personnel	15.5	6.3	16.3	17.8	14.3	14.3	14.3	14.3

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
Department of Health and Human Services								
Total operating	4.6	4.8	3.7	3.9	5.7	6.0	6.3	6.6
Technical personnel	28.9	26.7	26.1	25.4	25.0	25.0	25.0	25.0
Other direct personnel	0.4	0.4	0	0	0	0	0	0
Total direct personnel	29.3	27.1	26.1	25.4	25.0	25.0	25.0	25.0
Environmental Protection Agency								
Total operating	4.2	3.8	3.6	4.8	5.1	5.4	5.6	5.9
Technical personnel	23.3	20.3	20.0	20.0	20.0	20.0	20.0	20.0
Other direct personnel	2.4	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Total direct personnel	25.7	22.4	22.0	22.0	22.0	22.0	22.0	22.0
National Science Foundation								
Total operating	0.5	1.0	1.0	1.0	1.1	1.1	1.2	1.2
Technical personnel	2.6	2.2	2.4	2.0	2.0	2.0	2.0	2.0
Other direct personnel	*c*	0	0	0	0	0	0	0
Total direct personnel	2.6	2.2	2.4	2.0	2.0	2.0	2.0	2.0
Federal Emergency Management Agency								
Total operating	1.2	2.2	2.6	2.0	2.0	2.0	2.0	2.0
Technical personnel	9.6	2.6	5.0	5.0	5.0	5.0	5.0	5.0
Other direct personnel	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0
Total direct personnel	10.7	3.7	6.0	6.0	6.0	6.0	6.0	6.0
Agency for International Development								
Total operating	1.1	1.3	1.5	1.6	1.6	1.6	1.6	1.6
Technical personnel	4.8	4.4	5.0	5.0	5.0	5.0	5.0	5.0
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	4.8	4.4	5.0	5.0	5.0	5.0	5.0	5.0
Department of the Treasury								
Total operating	0.1	0	8.0	2.3	0	0	0	0
Technical personnel	10.9	17.8	12.8	10.9	6.9	10.4	2.2	0
Other direct personnel	0.4	0.5	1.6	0.5	0	0	0	0
Total direct personnel	11.3	18.3	14.4	11.4	6.9	10.4	2.2	0
Other Federal Agencies								
Total operating	2.3	3.3	3.3	3.4	3.4	3.5	3.5	3.6
Technical personnel	9.1	8.9	19.8	17.3	17.3	17.3	17.3	17.3
Other direct personnel	0.1	0.8	0.7	0.7	0.7	0.7	0.7	0.7
Total direct personnel	9.2	9.7	20.5	18.0	18.0	18.0	18.0	18.0

Table A.5 (continued)

	Fiscal year							
	1989	1990[a]	1991[a]	1992[a]	1993[a]	1994[a]	1995[a]	1996[a]
Electric Power Research Institute								
Total operating	3.6	1.7	2.0	2.0	2.1	2.2	2.3	2.4
Technical personnel	11.6	7.3	8.7	7.1	7.1	7.1	7.1	7.1
Other direct personnel	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3
Total direct personnel	12.1	7.8	9.0	7.4	7.4	7.4	7.4	7.4
Other Nonfederal Agencies[j]								
Total operating	13.6	4.2	4.0	4.0	2.4	3.1	3.2	3.2
Technical personnel	65.2	14.2	17.4	12.4	12.2	11.4	12.3	12.2
Other direct personnel	4.0	0.8	2.3	2.0	2.0	2.0	2.0	2.0
Total direct personnel	69.2	15.0	19.7	14.4	14.2	13.4	14.3	14.2
Total Work for Others[j,k]								
Total operating	92.2	91.4	122.9	121.6	100.7	103.1	102.9	103.7
Capital equipment	0	0	1.4	1.4	1.3	1.3	1.3	1.3
Total	92.2	91.4	124.3	123.0	102.0	104.4	104.2	105.0
Technical personnel	401.3	331.2	377.5	388.6	343.9	346.6	339.3	337.0
Other direct personnel	38.6	35.9	26.0	30.0	25.9	25.9	25.9	25.9
Total direct personnel	439.9	367.1	403.5	418.6	369.8	372.5	365.2	362.9
Total Program Resources[b,d,g,j]								
Total operating	429.9	455.6	608.5	666.9	547.6	541.1	547.4	546.2
Capital equipment	17.5	19.6	33.1	44.0	39.6	37.6	37.4	32.4
Construction	30.0	34.6	32.9	16.0	40.2	15.0	15.0	15.0
Total	477.4	509.8	674.5	726.9	627.4	593.7	599.8	593.6
Proposed construction	0	0	2.8	108.2	205.1	TBD	TBD	TBD
Technical personnel	1850.0	1746.2	2018.1	2213.9	1964.8	1982.7	1994.4	1951.2
Other direct personnel	234.4	205.1	268.5	300.9	250.3	225.3	220.1	218.4
Total direct personnel	2084.4	1951.3	2286.6	2514.8	2215.1	2208.0	2214.5	2169.6

[a]Escalation factors from FY 1990 to FY 1991 and from FY 1991 to FY 1992 are both 4.5%. Figures for FY 1993 through FY 1996 are in constant FY 1992 dollars.

[b]FY 1991 and FY 1992 data include two FWPs proposed in 1991 budget submission to cover OSHA and other safety and health compliance needs.

[c]Less than $0.1 million or less than 0.1 FTE.

[d]Includes ANS. TBD = to be determined.

[e]Also includes former KG environmental compliance projects that will be funded out of Program EX.

[f]Includes GPE or GPP funding from KG Program.

[g]The Applied Technology Division is included beginning in FY 1990.

[h]Beginning in FY 1990, the Isotope Production and Distribution Program is funded via a revolving fund through Program ST.

[i]Includes GPE or GPP funding.

[j]FY 1989 data include the Isotope Production Program, which is reported under Program ST beginning in FY 1990.

[k]Includes Nuclear Regulatory Commission. In addition, there are a few WFO projects that have ORNL staff as principal investigators, but part of the funding (~$5.3 million in FY 1990) is reported through the Y-12 and K-25 financial plans.

Acronyms

AA	Affirmative Action
ACL	Advanced Computing Laboratory
ACRD	Atmospheric and Climate Research Division
AEOD	Office for Analysis and Evaluation of Operational Data
AFEAS	Alternative Fluorocarbons Environmental Acceptability Study
AFESC	Air Force Engineering Services Center
AGMEF	Ana G. Méndez Educational Foundation
AI	artificial intelligence
AID	Agency for International Development
AIM	Accelerator Improvement and Maintenance
ANL	Argonne National Laboratory
ANS	Advanced Neutron Source
API	American Petroleum Institute
AR&TD	Advanced Research and Technology Development
ARIES	Advanced Reactor Innovation and Evaluation Study
ARM	atmospheric radiation measurement
ATD	Applied Technology Division
ATF	Advanced Toroidal Facility
ATR	Advanced Test Reactor
ATSDR	Agency for Toxic Substances and Disease Registry
BA	budget authorization
B&R	budget and reporting
BES	Basic Energy Sciences
BNL	Brookhaven National Laboratory
BOP	balance of plant
BRF	Bioprocessing Research Facility
BSR	Bulk Shielding Reactor
BTESM	Building Thermal Envelope Systems and Materials
BWR	boiling water reactor
C&TD	Computing and Telecommunications Division
CCP	Clean Coal Program
CDIAC	Carbon Dioxide Information Analysis Center
CDIARP	Carbon Dioxide Information Analysis and Research Program
CEF	Critical Experiments Facility

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CEQ	Council for Environmental Quality
CERN	Conseil Européen pour Recherche Nucléaire
CERR	Center for Excellence in Research Reactors
CESAR	Center for Engineering Systems Advanced Research
CFC	chlorinated fluorocarbon or chlorofluorocarbon
CFRP	Consolidated Fuel Reprocessing Program
CH	contact-handled
CHAMMP	Computer Hardware, Advanced Mathematics, and Model Physics
CIT	Compact Ignition Tokamak
CORECT	Committee on Renewable Energy Commerce and Trade
CRADA	Cooperative Research and Development Agreement
CRESO	Clinch River Environmental Studies Organization
CSAM	Center for Study of Advanced Materials
CURE	chemical unit record estimates
CVI	chemical-vapor infiltration
D&T	development and technology
DARPA	Defense Advanced Research Projects Agency
DC	direct cycle
DHHS	U.S. Department of Health and Human Services
DIMS	Data and Information Management System
DNA	deoxyribonucleic acid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE-BES	U.S. Department of Energy-Basic Energy Sciences
DOE-ER	U.S. Department of Energy-Energy Research
DOE/ID	U.S. Department of Energy, Idaho Falls Operations Office
DOE-ORO	U.S. Department of Energy-Oak Ridge Operations
DOE/SR	U.S. Department of Energy, Savannah River Operations Office
DOT	U.S. Department of Transportation
DSRD	Data Systems Research and Development
DTRC	David W. Taylor Naval Ship R&D Center
ECA	energy conversion area
ECH	electron-cyclotron heating
ECR	electron-cyclotron resonance
ECUT	Energy Conversion and Utilization Technologies
EDP	engineering development plan
EDA	engineering design activities

EGF	epidermal growth factor
EIA	Energy Information Administration
EMIC	Environmental Mutagen Information Center
EMP	electromagnetic pulse
EMPD	Engineering Physics and Mathematics Division
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
EPSSC	Environmental and Physical Science Study Center
ES&H	environment, safety, and health
ESC	Ecological Study Center
ESD	Environmental Sciences Division
ETP	Exploration Technology Program
FARS	Future Armor Rearm System
FDA	U.S. Food and Drug Administration
FEDC	Fusion Engineering Design Center
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIS	fluoroimmunosensor
FTE	full-time equivalent
FTIR	Fourier transform infrared
FUSRAP	Formerly Utilized Sites Remedial Action Project
GCM	general circulation model
GLCA/ACM	Great Lakes Colleges Association/Associated Colleges of the Midwest
GPP	general plant project
HASRD	Health and Safety Research Division
HAZWRAP	Hazardous Waste Remedial Action Program
HBCU	historically black colleges and universities
HERMIES	Hostile Environment Robotic Machine Intelligence Experiment Series
HFIR	High Flux Isotope Reactor
HGMIS	Human Genome Management Information System
HHIRF	Holifield Heavy Ion Research Facility
HISTRAP	Heavy-Ion Storage Ring for Atomic Physics
HLW	high-level waste
HTGR	High-Temperature Gas-Cooled Reactor
HTML	High-Temperature Materials Laboratory
HVAC	heating, ventilation, and air conditioning
HWR	heavy-water reactor

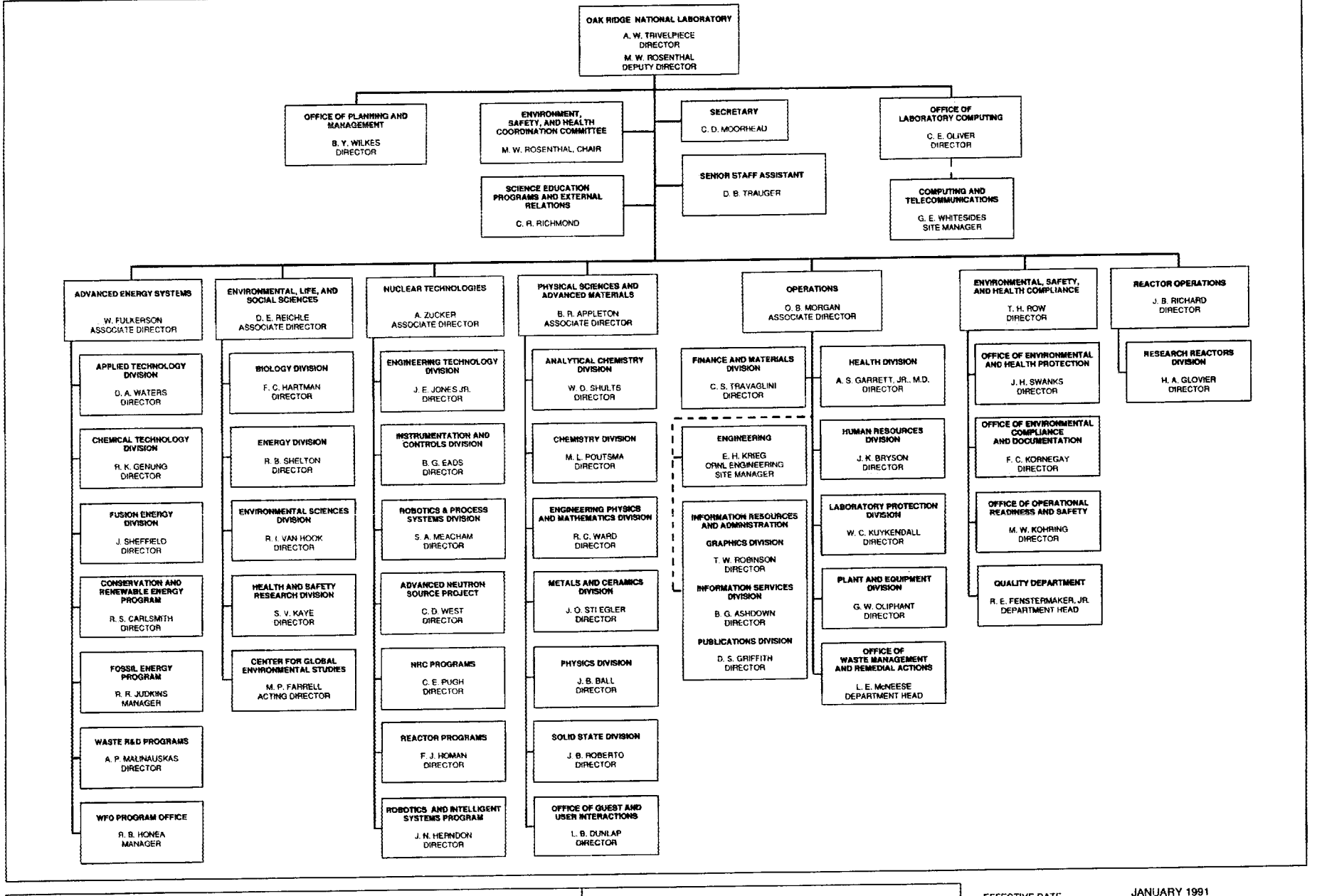
HPC	high-performance computing
IAC	Information Analysis Center
INEL	Idaho National Engineering Laboratory
IPM	(p-iodophenyl) maleimide
IRA	Information Resources and Administration
IRML	Isotopes Research Materials Laboratory
IRP	Installation Restoration Program
ITER	International Thermonuclear Experimental Reactor
IVHS	intelligent vehicle and highway systems
JASPER	Japanese/American Shielding Program of Experimental Research
LABCOM	U.S. Army Laboratory Command
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LET	linear-energy transfer
LLW	low-level waste
LMR	liquid metal reactor
LTM	Laboratory Telerobotic Manipulator
LWR	light-water reactor
MEI	minority education institution
MHTGR	Modular High-Temperature Gas-Cooled Reactor
MIRT	minority institution research travel
MOU	memorandum of understanding
MS&E	Materials Science and Engineering
MS/MS	mass spectrometry/mass spectrometry
MSDS	Material Safety Data Sheet
MSI	multisensor integration
MTMC	Military Traffic Management Command
NASA	National Aeronautics and Space Administration
NCA&TSU	North Carolina A&T State University
NCHGR	National Center for Human Genome Research
NEESA	Navy Energy and Environmental Support Activity
NEP	nuclear electric propulsion
NEPA	National Environmental Policy Act
NERC	NEPA Environmental Review and Compliance
NES	National Energy Strategy
NG	newly generated
NGB	National Guard Bureau
NMR	nuclear magnetic resonance
NMSS	Nuclear Material Safety and Safeguards

NPR	New Production Reactors
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
NSF	National Science Foundation/Neutron Scattering Facility
NTP	nuclear thermal propulsion
NUSC	Navy Underwater Systems Center
NWC	nuclear weapons complex
OCRWM	Office of Civilian Radioactive Waste Management
OEA	Office of Environmental Analysis
OGUI	Office of Guest and User Interactions
OHEA	EPA's Office of Health and Environmental Assessment
OHER	Office of Health and Environmental Research
ORA	Office of Risk Analysis
ORAU	Oak Ridge Associated Universities
ORDC	Oak Ridge Detector Center
ORELA	Oak Ridge Electron Linear Accelerator
ORGSBS	Oak Ridge Graduate School of Biomedical Sciences
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OTT	Office of Technology Transfer
OTD	Office of Technology Development
PC	personal computer
PCB	polychlorinated biphenyl
PNA	polynuclear aromatic (hydrocarbons)
PNC	Power Reactor and Nuclear Fuel Development Corporation (Japan)
PNL	Pacific Northwest Laboratories
R&D	research and development
RADCAL	Radiation Calibration Facility
RAPIC	Remedial Action Program Information Center
RCRA	Resource Conservation and Recovery Act
REDC	Radiochemical Engineering Development Center
RES	Office of Nuclear Regulatory Research
RETF	Recycle Equipment Test Facility
rf	radio frequency
RFTF	Radio Frequency Test Facility
RH	remote handled
RISP	Robotics and Intelligent Systems Program
RPP	Radiochemical Processing Plant

RSIC	Radiation Shielding Information Center
SACAM	Saturday Academy of Computing and Mathematics
SAHEP	Southern Association of High-Energy Physics
SARA	Service Academies Research Associates
SC	steam cycle
SCSS	Sequence Coding and Search System
SDI	Strategic Defense Initiative
SEED	Summer Educational Experience for the Disadvantaged
SEI	Space Exploration Initiative
SEPER	Science Education Programs and External Relations
SERS	Science and Engineering Research Semester
SFMP	Surplus Facilities Management Project
SMAC/CRC	Surface Modification and Characterization/Collaborative Research Center
SMART	Science and Mathematics Action for Revitalized Teachers
SNAP	Space Nuclear Auxiliary Power
SOCOM	Special Operations Command
SPC	Superconductivity Pilot Center
SPR	Strategic Petroleum Reserve
SRL	Savannah River Laboratory
SSC	Superconducting Super Collider
STAR	Summer Teachers as Resources
STEPS	Superconducting Technology for Electric Power Systems
STRIVE	Science Teachers' Research for Vital Involvement
SURA	Southeastern University Research Association
SWSA	solid waste storage area
TCE	trichloroethylene
TDHF	time-dependent Hartree-Fock
TDP	technology development plan
TEXTOR	Tokamak Experiment for Technically Oriented Research
TFTR	Tokamak Fusion Test Reactor
TIRC	Toxicology Information Response Center
TPP	Transuranium Processing Plant
TRA	Teacher Research Associates
TRU	transuranic
TSR	Tower Shielding Reactor
TVA	Tennessee Valley Authority
UE	Uranium Enrichment
UHV	ultrahigh vacuum

ULCP	University Laboratory Cooperative Program
UMTRAP	Uranium Mill Tailings Remedial Action Project
UPR	University of Puerto Rico
USEP	University and Science Education Programs
U.S.S.R.	Union of Soviet Socialist Republics
USTRANSCOM	United States Transportation Command
UTK	The University of Tennessee, Knoxville
UV	ultraviolet
UV-B	ultraviolet-B
VMT	vehicle-miles-of-travel
WFO	Work for Others
WHPP	Waste Handling and Packaging Plant
WIPP	Waste Isolation Pilot Plant
WRDC	Wright Research and Development Center
WSDD	Waste Systems Data and Development

REPORTS TO SENIOR VICE PRESIDENT



APPROVED *Al Trivelpiece*

ORGANIZATION CHART:

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA ENERGY SYSTEMS, INC.

EFFECTIVE DATE JANUARY 1991

MARTIN MARIETTA

Oak Ridge National Laboratory Organization Chart

Acknowledgments

The *Institutional Plan* is the final product of the Laboratory's 1990 planning cycle, which literally involved the efforts of hundreds of ORNL staff—from the researchers proposing individual projects, to program managers directing R&D areas, to Division Directors providing line management, to the Executive Committee establishing strategic directions. All of these researchers and managers also depended upon the skills and dedication of our able support staff—the financial officers, the information specialists, the computing staff, the administrative and secretarial staff, and many others.

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