ORNL/PPA--89/2

DE90 004905

Oak Ridge National Laboratory Institutional Plan FY 1990–FY 1995

Date Published—November 1989

Senior Planning Committee

A. W. Trivelpiece
M. W. Rosenthal
A. Zucker
C. R. Richmond
F. R. Mynatt
O. B. Morgan
B. R. Appleton
T. D. Anderson

Planning Staff

B. Y. Wilkes
C. A. Johnson
S. W. Hadley
J. R. Engel
R. A. Cantor
B. L. Burks
V. B. Baylor

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6285
operated by
Martin Marietta Energy Systems, Inc.
for the
U.S. Department of Energy
under Contract DE-AC05-84OR21400

DISCLAIMER

Contents

Laboratory Director's Statement

The change of Laboratory Directors has provided a good opportunity to reexamine the organization, function, and direction of the Laboratory. To meet the growing demands placed on the Director's office to respond to both administrative needs and scientific and technical opportunities, I have established a new position of Deputy Director. Murray Rosenthal, who has been with the Laboratory for 36 years and served as the Associate Director for Advanced Energy Systems for the last 15 years, has agreed to serve in this capacity.

A restructuring of the Laboratory organization at the Associate Director level was made in October 1989 to permit the Laboratory to focus on its long-term strategic objectives. The changes will also enable us to respond better to challenges arising from environmental, safety, and

Laboratory Director Alvin Trivelpiece talks to students participating in the precollege program during National Science and Technology Week.

health issues. As shown in the organization chart in the appendix, the Laboratory's six Associate Directorates are

- Operations;
- Chemical, Environmental, and Health-Protection Technologies;
- Nuclear Technologies;
- Advanced Energy Systems;
- Biomedical and Environmental Sciences; and
- Physical Sciences and Advanced Materials.

Also reporting to the Office of the Laboratory Director are the Office of Planning and Management, Reactor Operations, and two newly established entities: the Office of Laboratory Computing and the Environment, Safety, and Health Coordination Committee. Further organizational adjustments will be made at both the division and program levels in FY 1990.

A key component in the future of ORNL is the strength of its multidisciplinary expertise. Nationally, the priorities and expectations of the DOE laboratories are changing. ORNL has the resources and capabilities to make a major contribution to the solution of the scientific and technical challenges that face us. The creativity and energy I have seen since my arrival convinces me that the future of ORNL is bright.

The R&D initiatives proposed in this document represent important steps to further the missions of DOE and ORNL. The initiatives themselves show the diversity and breadth of the Laboratory—from its basic physical and life sciences research to its applied research in waste R&D and energy technologies to advanced materials R&D to isotope production and to energy policy assessments.

All of the proposed initiatives are both important to DOE and the United States and draw upon ORNL's unique combination of expertise. For example, ORNL's experience in waste-related R&D makes the Laboratory a natural contributor to this critical area. Because of this national need and our capabilities, a new waste research, development, and demonstration initiative is being proposed, and the Waste R&D Program office is now reporting directly to the Associate Director for Chemical, Environmental, and Health-Protection Technologies.

The Center for Global Environmental Studies, a focal point of another initiative, was recently established to focus the Laboratory's resources more strongly on important environmental issues that are larger in spatial scale and operate over longer time periods than traditional environmental concerns. These issues, heightened by current attention to possible global warming as a consequence of the "greenhouse effect," include climate change, ozone depletion, globally distributed contaminants, ocean pollution, deforestation, loss of biodiversity, resource depletion, erosion, and desertification. The center will serve to match our research strengths with particular global issues and their associated sponsors for national and international collaborative research and assessment activities.

Several other initiatives will provide for expansion of research capabilities. The Advanced Neutron Source is continuing in its design phase and will provide a new, world-class research reactor for neutron research and isotope production. A DOE panel has recommended that the Gammasphere, a national gamma-ray facility, be constructed at Oak Ridge. The Heavy Ion Storage Ring for Atomic Physics would allow further study of the physics of multiply charged ions. The Molecular Genetics Laboratory, a proposed FY 1992 line-item project, will provide an advanced-level research facility and begin to relocate the Biology Division to the X-10 site. The initiative on grand challenges in computational science would establish a center to take advantage of ORNL's expertise in parallel computing research and in specific computing intensive applications, together with the experimental computer hardware, to solve important computational problems in science and engineering.

The Superconducting Supercollider (SSC) that will be built in Waxahachie, Texas, will require the development of new, highly efficient detector systems. With ORNL's expertise in detector R&D, I believe the Laboratory should be one of the centers where the SSC detector research, development, design, and construction occur. To that end, the Laboratory is establishing a High Energy Physics Research and Detector Development Center.

ORNL is known for its materials work. Several of our initiatives draw upon the Laboratory's broad multidisciplinary strength in this area. The Advanced Research Center for Materials Science and Engineering will bring together the southeastern materials research community to explore ways to simplify and encourage joint materials research activities with ORNL. Similarly, in the high-temperature superconductor R&D initiative, the Laboratory is working closely with U.S. industry to accelerate the commercial application of these new, high-temperature superconducting materials. Another initiative, microwave sintering of ceramics, is developing a new technique for controlling microstructure to improve the properties of advanced ceramics.

ORNL is also an energy technology laboratory. Several of our initiatives build on our years of experience in this area, including our initiatives in waste RD&D, energy technologies for developing nations, modular high-temperature gas-cooled reactor technology development, advanced reactor control systems, and bioprocessing.

The initiative to modernize the Isotopes Program would reequip and modernize the radioisotope processing capabilities at ORNL so that we could continue to process and supply radioisotopes in an acceptably safe manner.

To continue as an important research institution, ORNL must have adequate facilities. A continuing challenge for all DOE facilities is the replacement and refurbishment of aging structures. This includes not only research facilities but also the physical plant and utilities. It is imperative that we continue our efforts in environmental, safety, and health upgrades to attain the proper level that allows our excellent research activities to be continued with full protection of our staff and the environment.

Our role as a "change agent" at the national level will continue as the unique facilities at ORNL are used by an increasing number of researchers from university and industry. We need to enhance our understanding of industry problems if we expect significant progress toward solving national competitiveness issues. Working with educators at all levels is increasingly needed to convince youth, including females and minorities, that science and engineering careers are important.

The principal challenge that overarches all the other Laboratory activities is the ability to retain and recruit outstanding leaders in science and engineering in various research areas and in advanced technology development. This will be crucial especially in those areas that the Laboratory wants to emphasize and lead. The competition for such individuals is going to get tougher over the next 10 years. We must do what we can to help ensure that an adequate supply exists through our contributions to national education activities and that we are able to recruit an adequate number of those so trained. This scientific and technical workforce will include an increasing number of women and minorities. In planning for our future workforce, as in planning all aspects of our program, we must have an uncompromising commitment to the pursuit of excellence.

Laboratory Missions

The Oak Ridge National Laboratory is one of DOE's major multiprogram energy laboratories (Fig. 1). ORNL's program missions are (1) to conduct applied research and engineering development in support of DOE's programs in fusion, fission, fossil, renewables (biomass), and other energy technologies, and in the more efficient conversion and use of energy (conservation) and (2) to perform basic scientific research in selected areas of the physical and life sciences. These missions are to be carried out in compliance with environmental, safety, and health regulations. Transfer of science and technology is an integral component of our missions. A complementary mission is to apply the Laboratory's resources to other nationally important tasks when such work is synergistic with the program missions. Some of the issues addressed include education, international competitiveness, hazardous waste research and development, and selected defense technologies. In addition to the R&D missions, ORNL performs important service roles for DOE; these roles include designing, building, and operating user facilities for the benefit of university and industrial researchers and supplying radioactive and stable isotopes that are not available from private industry.

Scientific and technical efforts in support of the Laboratory's missions cover a spectrum of activities. In fusion, the emphasis is on advanced studies of toroidal confinement, plasma heating, fueling systems, superconducting magnets, first-wall and blanket materials, and applied plasma physics. The ORNL nuclear fission activities

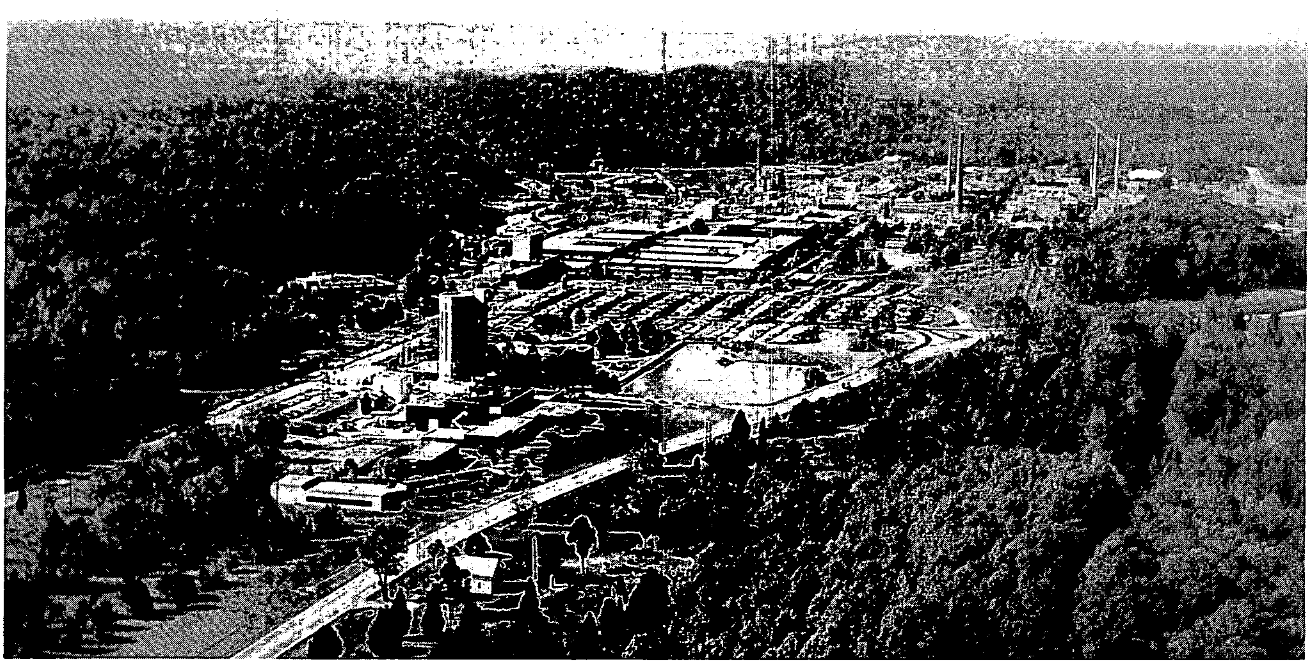


Fig. 1. The Oak Ridge National Laboratory, X-10 site.

support DOE's civilian nuclear power program through R&D on nuclear fuel reprocessing, high-temperature gas-cooled reactors, instrumentation and controls, nuclear and chemical wastes, and materials. ORNL is responsible for providing technical assistance to the New Production Reactor Program. The Laboratory's program on the efficient use of energy emphasizes research on high-temperature and other advanced materials, R&D for improving electric power transmission and distribution systems, technologies for increasing the efficiency and economical use of energy in buildings and industry, and energy storage at high and low temperatures. Biomass R&D emphasizes the development of techniques to reduce the cost and increase the productivity of woody and herbaceous feedstocks applicable to many regions across the country and in developing nations. ORNL's fossil energy work concentrates primarily on materials and on innovative research in coal conversion and utilization with a major emphasis on bioconversion processes. Basic and applied research in the physical, social, informational, and life sciences provides the foundation for the technology development work.

Biological and environmental research emphasizes the interaction of energy-related physical and chemical agents with the environment and with living organisms. Research in the information field includes work on expert systems, simulations, and decision research. In the physical sciences, basic and applied research areas include high-temperature materials; neutron scattering; surface physics; aqueous, separations, analytical, and environmental chemistry; robotics; parallel computing; and heavy-ion nuclear and atomic physics. Social science research includes behavioral analyses that are important for emergency response plans and studies on the social impacts and causes of environmental changes.

The role of providing user facilities for industry and universities encompasses over a dozen major installations, including the Neutron Scattering Facility, the National Center for Small-Angle Scattering Research, the Holifield Heavy Ion Research Facility, the High Temperature Materials Laboratory, the Surface Modification and Characterization Collaborative Research Center, the Health Physics Research Reactor, the National Environmental Research Park, and other important user facilities related to energy technologies and the sciences. In the area of education, emphasis is given to research involvement by students, teachers, and faculty of all levels.

Laboratory Strategic View

The next 15 years promise to be a very exciting and productive period in the history of ORNL. It will be a period of revolutionary changes in science and technology with unparalleled opportunities for applying these developments to improve the human condition. The ORNL staff and management have always believed that the purpose of the Laboratory is to serve important national needs. The intersection of important national needs with ORNL's R&D capabilities represents the broad direction we want to take over the next 15 years.

Planning Assumptions

Some future trends and events are controllable by the Laboratory. Others are not. The following discussion of planning assumptions focuses on those future conditions that are outside our control, but that influence what we do.

External

Indications are that two major trends will converge early in the next decade to present the nation with a challenge of significant proportions. First, the current deficiencies of the United States in international commerce will probably continue and may even worsen. Second, it is highly probable that the current trend of rising oil imports, coupled with Middle East instabilities, will lead to heightened concern about energy by the mid-1990s. The convergence of increased reliance on imported oil and the inability to compete in international markets will cause significant stress to the U.S. economy. Unlike the conditions of the 1970s, when the United States' positive trade balance for manufactured goods helped to offset the trade deficit related to oil, the 1990s will very likely be characterized by huge deficits in both categories. If this scenario becomes reality, the social and political pressures for change will be large. In particular, the traditional sharp boundaries between the roles of industry, government, and universities will become intentionally blurred as it becomes painfully evident that the challenge of global economic competition will require the nation to call upon all of its intellectual resources—universities, industry, and national laboratories—to work together toward a common goal.

DOE and its national laboratories will become more important in the quest to restore a favorable balance of trade. First, DOE possesses the country's largest collection of scientific and technical talents and research facilities, and most observers believe that the mobilization of these resources is a key ingredient to the future health of U.S. industry. An even more obvious reason DOE and its laboratories are important is that energy products and energy technologies are, and will continue to be, two of the largest components of international trade. For the United States, oil imports will be the single largest contributor to the negative balance of trade.

We realize that these same economic forces and the concomitant congressional effort to shore up the budget deficit gap will tend to tighten up government spending on science. Competition for science funds will intensify. We are optimistic that DOE's laboratories will continue to receive their fair share of the limited funds. The U.S. science dollars will be stretched with the increased collaboration among all R&D sectors, and the national laboratories will act as catalysts to make this happen.

In another area important to DOE and its laboratories, the issues related to hazardous chemical and radioactive wastes will increase in importance nationally throughout this century and beyond. DOE's interest in these areas stems from (1) the need to clean up its own facilities and (2) the responsibility for safe management of radioactive wastes from the nuclear fuel cycle. The techniques and technologies for neutralizing existing waste sites will, for the first half of the planning period, be the highest-priority objectives of national R&D programs on wastes. But the high cost of cleanup will lead to research on processes that produce fewer wastes and less environmental damage (Fig. 2). Results from R&D work directed toward DOE's waste problems will, in many instances, be transferable to national waste problems. DOE and its laboratories will continue to escalate resources on the actual cleanup of its facilities, including ORNL. Considerable progress will be made in the next decade.

Concurrent with the worsening energy and trade trends and the increased emphasis on wastes will be a decline in federal expenditures for the production and deployment of weapon systems, including nuclear weapons. The decline in defense spending will be influenced partly by arms control agreements with the Soviet Union. Even though defense spending will decline, funding for R&D on

Fig. 2. In situ biological degradation. ORNL is conducting research with microbial cultures obtained from PCB-contaminated soils to learn how to enhance the natural PCB-degrading activity.

advanced defensive weapon systems will continue at a relatively high level.

The consequences of these trends and events will be a restructuring of national priorities, including those of DOE and its national laboratory system. Nuclear weapons production and spending for that activity will decline. Basic research will continue at a relatively high level but with a lower priority, although some areas will grow. Applied research and engineering development on energy technologies and other technologies of importance to the trade issue will be elevated to the highest priority. Developmental activities that move a technology toward a commercial product will be encouraged. More emphasis will be placed on collaborative R&D involving DOE's laboratories and industry. There will be less concern about maintaining separation of industry and government and more concern about restoring the United States to a leading role in international commerce.

Closer to home, the southeastern United States is becoming a preferred region for industrial growth, and its educational structure is growing. ORNL is a drawing card in bringing industry and educational organizations to the Southeast; reciprocally, the Laboratory will continue to benefit from the region's emerging leadership in economic development and educational excellence.

Laboratory Environment

Five themes will dominate ORNL's directions during the next one and one-half decades: energy; competitiveness; global environmental effects; collaborative research based on the Laboratory's unique user facilities; and environment, safety, and health concerns. ORNL will remain a DOE-owned, contractor-operated institution. It is assumed that DOE will continue to depend on the Laboratory for R&D and other services similar to those presently provided and that ORNL will retain its current basic roles and missions. Although energy R&D will remain the centerpiece of ORNL's programs, the Laboratory will have major roles in basic sciences, waste R&D, and defense technologies. About 80% of the Laboratory's effort will be in support of the missions of DOE and the Nuclear Regulatory Commission. Work for other government agencies and for private industry will consist of R&D activities that are important to the nation and that complement DOE's programs.

Activity Trends

Overall Trends

Even though continuity in basic missions is expected, the Laboratory will nevertheless undergo major changes. One of the driving forces for change will be the growing role of DOE and its national laboratory system in helping American industry to regain a leading position in international commerce. This role will cause some R&D activities at ORNL to be carried much further toward commercial products and processes than has been true in the 1980s. Much more thought and effort will be given to moving technological innovations to the marketplace. Patents on technologies and exclusive licenses to industry will be commonplace. Collaborative research, centered around major user facilities, will become a very important component of the Laboratory's intellectual output.

As the national priorities shift toward civilian technologies, the character of the Laboratory will change. It will become larger, and there will be a greater emphasis on major technological missions in energy and other commercially important technologies. Slight changes in sponsorship will occur, with the most notable shift being an increase in work for private industry.

As a consequence of the emphasis on collaborative R&D, the population of guest researchers at ORNL will continue to increase. By the year 2005, the number of guest researchers will approach 4500, about double the number (2304) for 1988. Much of the increase in collaboration with outside researchers will be associated with the expansion of existing user facilities and the addition of new facilities. Major new facilities to be put in operation over the next 15 years will include the Advanced Neutron Source (ANS) (Fig. 3), the Heavy Ion Storage Ring for Atomic Physics (HISTRAP), the Gammasphere, the Advanced Control Test Operation (ACTO) facility, and some important experimental fusion facilities.

The Laboratory is strongly committed to ensuring that its programs are conducted in compliance with environmental, safety, and health regulations and to cleaning up any environmental problems from past programs. Remediation will require the continued effort of DOE and the Laboratory over the next 15 years and beyond.

Energy Technologies

The Laboratory will strive for strong, balanced programs in all major energy technology areas—efficiency improvements (conservation), fusion, fission, fossil, and biomass.

Conservation and Renewables (Biomass)

Improvements in energy efficiency and development of economic renewable resources offer some of the most important opportunities for increasing economic competitiveness and national security in an environmentally acceptable manner. Long-term Laboratory goals are to continue our leadership role in all sectors of energy conservation and to develop technologies for widespread utilization of biomass energy. Specific emphasis areas over the next 15 years will be

- developing technologies for efficient building envelopes and heat pumps;
- continuing advanced materials development for applications to transportation systems, industrial processes, and buildings;
- developing materials for practical high-temperature superconductors for applications such as electric motors;
- exploiting the technical and economic potential of sintering ceramics with microwave energy;

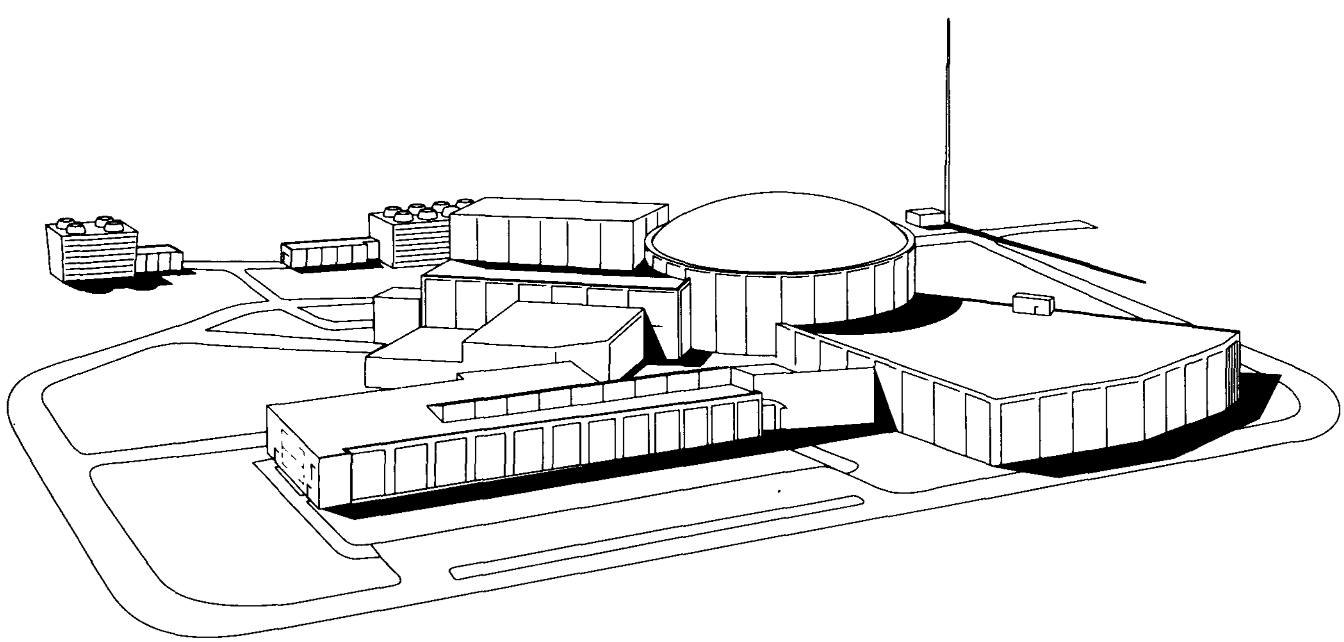


Fig. 3. The ANS will be a new experimental research reactor facility designed to meet national needs for an intense, steady-state source of neutrons. The facility will be open for use by scientists from universities, industry, and other laboratories throughout the world. The project is currently in the conceptual design phase, with design completion and construction to occur during 1994–1998.

- assisting industry through the operation of the High Temperature Materials Laboratory and Roof Research Center user centers; and
- attaining economic competitiveness in the production and conversion of biomass energy.

Fusion

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 the potential of fusion into reality. The Laboratory's long-term strategy for fusion is to stress scientific and engineering excellence in a broad program emphasizing confinement, theory, technology, and materials. ORNL's major 15-year goals in fusion are

- to maintain leadership in advanced plasma technology components,
- to establish a strong program in remote technology for fusion,
- to be a primary leader in materials development and testing for fusion reactors,
- to maintain U.S. leadership in stellarators, and
- to increase the potential of Oak Ridge as a site for major fusion facilities by participating in the physics, engineering, and development for the Compact Ignition Tokamak (CIT) and the International Thermonuclear Experimental Reactor (Fig. 4).

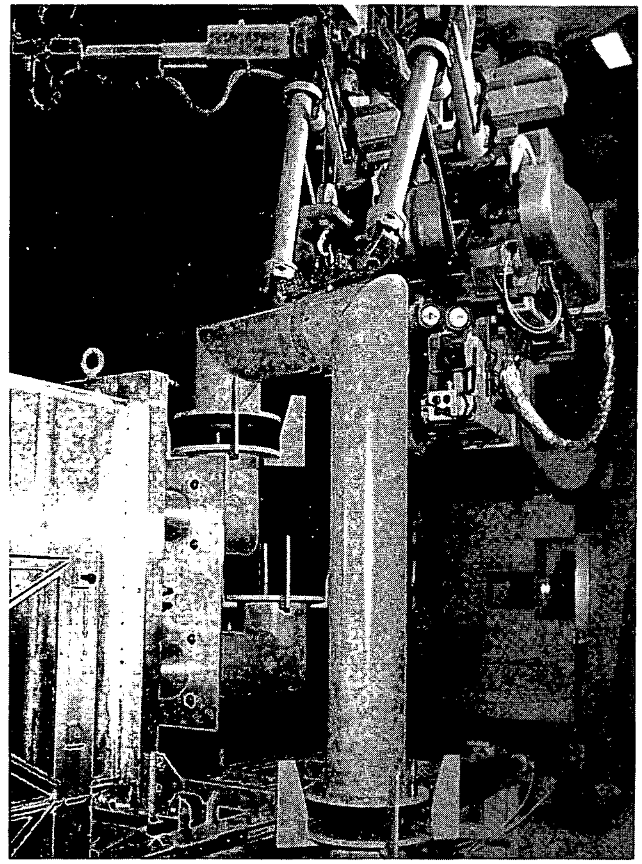


Fig. 4. M-2 servomanipulator replacing coax for CIT/ICH mockup.

Fission

Planned directions for ORNL in fission energy R&D include leading roles in modular high-temperature gas-cooled reactor (MHTGR) technology, nuclear fuel reprocessing, improvements to existing light-water reactors, and selected areas of reactor safety research. The Laboratory will also play a supporting role for all reactor concepts through its work on strategic technologies, including

- advanced instrumentation, control, and automation;
- robotics and teleoperations;
- high-temperature materials and structural design;
- advanced shielding methods and materials;
- fuels and cladding;
- fission product transport; and
- severe accident analysis.

ORNL will also play an important role in the emerging New Production Reactor (NPR) Program as Center of Excellence for HTGR fuels and fission product transport and for materials and structural design and instrumentation and control for both the heavy-water reactor and HTGR concepts. In addition, ORNL will serve as lead Laboratory for Engineering Economic Analysis, Codes and Standards, and ad hoc technical support to the NPR Program Office.

Fossil

Fossil energy R&D will focus on materials, environmental safety and health, and advanced coal processing concepts, including the bioprocessing of coal. Materials work will include research on

- ceramic composites for high-temperature structural applications and hot-gas filters,
- ceramic membranes for gas separation,
- advanced austenitic alloys for second-generation power plants;
- advanced intermetallic alloys for high-temperature corrosive environments, and
- mechanisms of materials erosion and corrosion.

Environmental safety and health research will include support for the Clean Coal Program in the preparation of environmental documentation, such as environmental impact statements and environmental assessments, to satisfy the requirements of the National Environmental Policy Act. A dilemma of coal combustion is that it contributes to a build-up of CO_2 in the atmosphere. Hence, R&D will emphasize improving the efficiency of conversion. Work in advanced coal processing concepts will include studies of mild gasification processes and a major R&D effort on the bioprocessing of coal, including both liquefaction and gasification, as well as fundamental studies.

Other Technologies

Space and defense technologies and waste R&D will become important components of the Laboratory's activities within the next 15 years. Areas of work on space and defense technologies will be closely related to ORNL's civilian R&D roles. Examples of areas for future emphasis are space applications of robotics and teleoperations, engineered materials, space structures, and survivable space optics.

The planned program in waste R&D is strongly oriented toward supporting DOE's missions in this area. The scope includes chemical, radioactive, and mixed wastes.

The Sciences

The Laboratory will maintain vital programs in both the physical and life sciences over the planning period. The science programs serve two purposes: they add to the storehouse of fundamental knowledge, and they create a strong scientific base in support of the Laboratory's technology programs. In addition, ORNL's social scientists will continue to contribute to the understanding of technological change, as many of the policy issues are related to behavioral responses rather than to technical problems.

Physical Sciences

Areas of research in the physical sciences will include

- materials science and engineering;
- mathematics and computations;
- robotics and intelligent systems;
- nuclear, atomic, and high-energy physics; and
- the chemical sciences.

The goals of the Laboratory's materials program are to excel internationally in high-temperature materials development and to excel in certain areas of solid state physics, including surface research, preparation of new materials, advanced material processing, and neutron scattering. One area of emphasis in computations will continue to be research on parallel processing. In robotics and intelligent machines, research topics will include teleoperations and autonomous systems, with man-machine symbiosis as the ultimate goal. Heavy ion research, including operation of the Holifield Heavy Ion Research Facility (HHIRF) as a national user facility, will continue to be the centerpiece of the nuclear physics program at the Laboratory. Major new detector systems will be developed for the HHIRF, including the Gammasphere and the Recoil Mass Separator. In atomic physics, the addition of HISTRAP will extend the research program to new regimes of ion-atom and ion-ion collisions. As the Superconducting Supercollider Project is established nationally, ORNL's high-energy physics research will expand along with multidisciplinary detector development activities. The chemical sciences will stress four major areas (1) chemistry of and with radioactive materials, (2) environmental chemistry and waste technology, (3) materials chemistry, and (4) separations sciences.

Life Sciences

The life sciences—biology, health and safety research, and the environmental sciences—will continue as essential elements of the Laboratory's activities throughout the 15-year strategic planning period (Fig. 5). An important objective is to study and understand the interactions of physical and chemical agents with living organisms, including transport, chemical evolution, adverse health effects, and ultimate consequences to humans and their environment.

In biology, the plan is to build on the core areas of

- mammalian and molecular genetics,
- radiation carcinogenesis, and
- protein engineering.

In addition, the Laboratory plans to expand multidisciplinary research in structural biology and genome-related research.

Work in health and safety research provides a sound scientific basis for measuring and assessing the impacts of radiological and chemical substances on human health. Efforts are focused on

- improving human health risk analysis,
- developing nuclear medicine applications,
- improving measurement techniques, and
- developing information research and analysis in association with the R&D activities at ORNL.

Important long-term goals in environmental research are

- to anticipate future environmental problems,
- to understand atmosphere-biosphere boundary interactions and feedbacks,
- to improve time-space scaling of nonlinear environmental systems and regional extrapolation,
- to develop predictive environmental models,
- to understand mechanisms of subsurface transport,
- to understand global environmental systems, and
- to quantify environmental risk and cumulative effects.

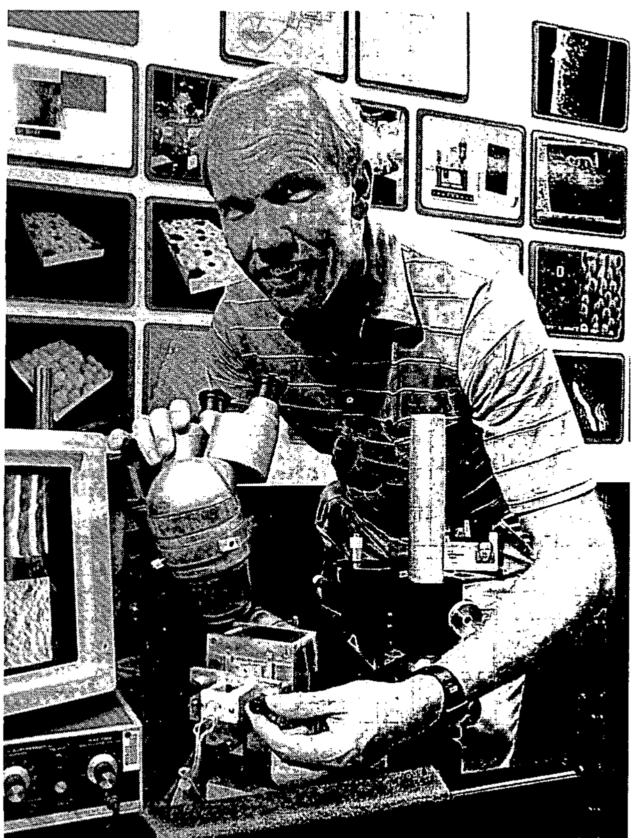


Fig. 5. ORNL is at the forefront in the use of the scanning tunneling microscope for life sciences research. ORNL scientists Bruce Warmack (pictured) and Tom Ferrell recently won an R&D 100 Award for the development of this photon scanning tunneling microscope, which is being used in several areas of life sciences research at the Laboratory.

Managerial Implications

Changes of the magnitude suggested by this plan will present significant management challenges to both DOE and ORNL over the next 15 years. Management attention will be required in several areas, including physical facilities; equipment needs; human resources; environmental, safety, and health issues; and site restoration and development.

Central to accomplishing the missions outlined in this plan is the acquisition of key research facilities. The ANS is of critical importance to a number of the Laboratory's research areas, including materials, nuclear engineering, biology, and the chemical sciences. The HISTRAP and the Gammasphere are keys to maintaining the HHIRF as a state-of-the-art user facility. An important part of the Laboratory's contributions to DOE's nuclear missions will be advanced-control R&D centered around the ACTO facility. Completion of the Life Sciences Complex is essential to achieving the biological research objectives. The Molecular Genetics Laboratory will be an important addition to the Life Sciences Complex.

One of the highest-priority management objectives is to bring a first-rate computing environment to the Laboratory's research staff. Both equipment and development funding will be required to bring about a modern distributed computing system consisting of powerful workstations and special-purpose central machines linked by high-bandwidth data networks.

DOE's and the Laboratory's commitment to ensuring that its facilities are operated in compliance with all federal and state environmental, safety, and health regulations will continue to be a high priority for ORNL and Energy Systems management and staff.

The Laboratory management will need to give considerable attention to office and laboratory space, cafeteria facilities, parking space, and other support facilities. Expansion is required in support facilities to accommodate an increase of 50 to 100% in the resident research staff during the next 15 years. Part of this increase will come from adding new employees, but a larger component will be from growth in the number of guest researchers.

ORNL's education and training programs will continue to grow and to serve an increasing number of students, teachers, and staff. DOE and Laboratory management need to work together to ensure that this highly successful program is allocated the resources and facilities it requires to help prepare the scientific and technical workforce of the future.

Perhaps the most significant management challenge of all will be to learn how to help American industry turn the results of government-sponsored R&D into commercially important products. This will require interactions between the Laboratory and industry on an unprecedented scale. New institutions and new ways of dealing with old institutions will be needed. Major reforms will be required in administrative, legal, and contractual policies and procedures.

Initiatives

Research and development, as a creative and renewing process, feeds on new ideas such as the new research areas described in the initiatives ORNL is proposing. These initiatives have two common ingredients: (1) they are needed to increase scientific knowledge or to address important national (or international) needs, and (2) ORNL, with its broad interdisciplinary strengths, is particularly well suited to undertaking them.

We appreciate the opportunity to formally propose these initiatives, which are provided for DOE's consideration. Their inclusion in this document does not imply either DOE's approval or its intent to implement them.

New Initiatives

Advanced Research Center for Materials Science and Engineering

Materials science and engineering is a prominent area of opportunity for science in the United States in the 1980s and 1990s. 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 science to materials engineering and testing. Similarly, ORNL has perhaps the strongest materials R&D program among the DOE national laboratories. In addition, ORNL operates a number of user facilities that benefit directly from interactions with university and industry programs. During the last few years, the Southeastern Universities Research Association (SURA) and Oak Ridge Associated Universities (ORAU) have explored ways to simplify and encourage joint materials research activities with ORNL. This approach would not only benefit already large, well-established programs but also would enhance individual small programs at the universities through synergistic interactions.

As the result of a SURA materials science workshop and other organizational meetings between SURA and ORAU, it was concluded that the establishment of a campus-like presence at ORNL in the form of an Advanced Research Center (ARC) for Materials Science and Engineering would be the best approach to serve the needs and goals of the member universities. The goals of ARC 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 important to both DOE and university participants that transcend the capabilities of a given institution. A proposal is being developed for ARC 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 and national laboratory researchers. The center is intended to make the entire materials science and engineering opportunities of ORNL more easily accessible to the southeastern institutions and to provide positions for visiting scholars, faculty, and graduate students for research and study. The SURA Communications Network could be tied into ARC to provide ease of scientific interchange through broadcasts of seminars, lecture series, workshops, and other significant technical presentations or discussions.

The operation of ARC would be carried out through the cooperation of SURA, ORAU, and ORNL. An informal summer program was established at ORNL for 1989 that included faculty and graduate students from several universities. The cost was shared by ORNL and participating universities. This summer program will also be used to initiate planning for the formal ARC proposal. Some of the issues to be resolved include the treatment of technical data rights, patent rights, and procedures for performance of proprietary research. Support for ARC is envisioned as joint funding from DOE Basic Energy Sciences (BES), the National Science Foundation's (NSF's) Division of Materials Research, and state funds from the participating universities. Establishment of ARC would involve construction of a building adjacent to ORNL at an approximate cost of $50 million, with projected operating costs of $10 to $15 million per year (Table 1). (At this point detailed estimates are not available. Construction and operating costs are cited above only to indicate the relative scope of the concept being proposed.)

High-Energy Physics Research and Detector Development Center

Successful utilization of the Superconducting Supercollider (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. It 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.

ORNL has a long history of expertise in detector R&D and has projects under way in several divisions that are related to current high-energy physics detector problems. However, ORNL has historically staffed a relatively small number of researchers in high-energy theory and experimental research. Several universities in the southeastern part of the United States have active programs in high-energy physics that use currently available facilities and have a strong interest in being major users of the SSC. Consequently, an association of these universities, the Southern Association of High-Energy Physics (SAHEP), has proposed the establishment of a cooperative effort between SAHEP and ORNL to design and build a high-energy detector system for use in an associated R&D program on SSC.

The SAHEP has proposed the establishment of a High-Energy Physics Research and Detector Development Center located at ORNL. Siting the

Table 1. Budget projections by fiscal year for the Advanced Research Center for Materials Science and Engineering ($ in millions)

	1988	1989	1990	1991	1992	1993	1994	1995
Operating	0	0.5	1.0	2.0	10.0	15.0	15.0	15.0
Capital equipment	0	0	0	0	2.0	2.0	2.0	2.0
Line-item construction	0	0	0	5.0	50.0	0	0	0

center at ORNL will take advantage of existing multidisciplinary resources, including research, engineering, instrumentation, computing, fabrication, and testing facilities required to make and test such a large, complex system. The associated universities would provide the center with participating scientists to facilitate design of the detector at ORNL and would take the lead in planning the high-energy physics research program. Successful completion of this task will require close cooperation of the partners and selective enhancement of the faculty and staff at both the participating universities and ORNL in areas found critical to the proposal.

The SAHEP, in close cooperation with ORAU, SURA, and ORNL, would organize the center early in FY 1990 and prepare proposals to DOE and SSC as soon as practicable. The estimated scope of this project depends on funding for the SSC. Initial funding will come from DOE High-Energy Physics and the SSC Project and will include funds from the state of Texas as well as international participants.

In addition to the regional universities affiliated with SURA, ORAU, and SAHEP, a number of individual universities outside the southeast region have also expressed interest in collaborating with ORNL on SSC-related projects. The nature and extent of these collaborations 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 (Table 2).

Gammasphere

Gammasphere is a proposal for the construction of a national gamma-ray facility that would 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. 6). 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.

Gammasphere is being 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 (DOE-ER). 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 would be located at the HHIRF. Building modifications to HHIRF of approximately $750,000 would be provided out of ORNL general-plant-project funds to accommodate the detector system. Current planning calls for decreased funding at some DOE nuclear physics facilities to accommodate operating costs for new facilities; therefore, selection of the site for Gammasphere could have implications for

Table 2. Budget projections by fiscal year for the High-Energy Physics Research and Detector Development Center ($ in millions)

	1988	1989	1990	1991	1992	1993	1994	1995
Operating	0.2	0.3	1.0	2.0	3.0	3.0	3.0	3.0
Capital	0.0	0.04	0.2	0.5	1.0	1.0	1.0	1.0

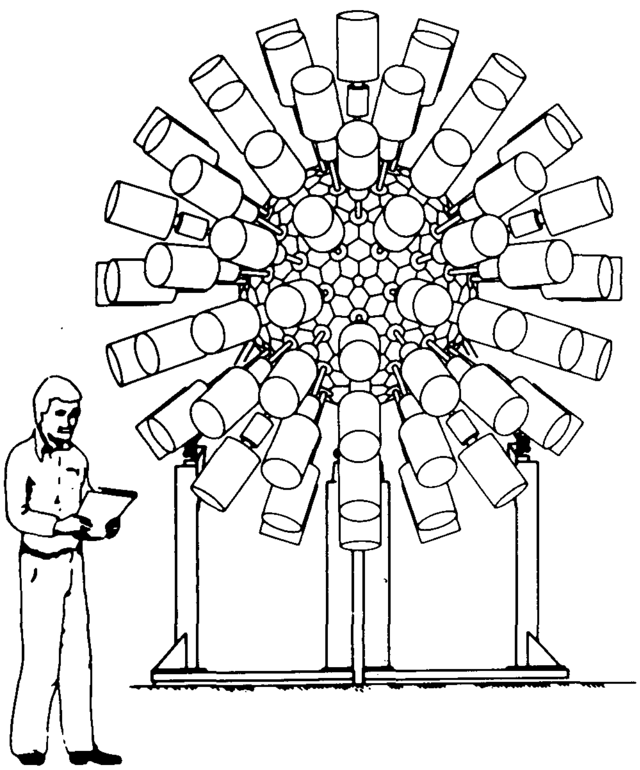


Fig. 6. Sketch of the Gammasphere detector system.

the level of future support at HHIRF. If the HHIRF is chosen as the site for Gammasphere, site preparation and operating costs will be less than the projections for other sites. Construction funds for Gammasphere are requested for the FY 1991–1993 period with operation to begin in FY 1994 (Table 3).

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. 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, but 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 to establish a Center for Grand Challenges in Computational Science. The purpose of the center would be to take advantage of ORNL's unique resources to provide the combination of expertise in parallel computing research and in specific computing intensive applications, together with the experimental computer hardware, necessary to solve important computational problems in science and engineering. The selection of applications problems to address would be based on four criteria:

1. The problem is of fundamental importance, and its solution would be of great value to science.

Table 3. Budget projections by fiscal year for the Gammasphere ($ in millions)

	1989	1990	1991	1992	1993	1994	1995
Operating	0.2	0.2	0.2	0.3	0.4	1.1	1.1
Capital						0.2	0.2
GPP construction			0.75				
Line item construction			5.5	6.0	5.5		

2. For adequate accuracy and resolution, the problem requires massive computation, well beyond the capacity of today's supercomputers.
3. The problem is amenable to the effective exploitation of massive parallelism.
4. ORNL is in a unique position to make significant progress on the problem.

ORNL, as a multipurpose national laboratory, has several research problems that satisfy the above criteria. Inclusion of these problems in the center will be accepted as long as sufficient resources are available. A partial listing of potential ORNL grand challenges includes

- calculation from first principles of the physical properties of high-temperature superconductors,
- modeling of lepton pair production in heavy-ion collisions,
- global climate modeling,
- fluid flow through porous media and other problems related to environmental cleanup, and
- design and analysis of particle detectors for the SSC.

ORNL already has in place the personnel to form interdisciplinary teams to carry out the grand challenge projects. A solid core of expertise in parallel computing research exists in the Mathematical Sciences Section of the Engineering Physics and Mathematics Division, and numerous other qualified individuals work in 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. Our primary need at present is for a world-class, massively parallel supercomputer on which to implement such large-scale projects. The parallel computers currently available at ORNL are suitable for pilot implementations to gain experience with parallel computing technology, but they do not have the necessary power to make a serious dent in the computational needs of the envisioned projects. Even modest-size problems of realistic complexity require days or weeks to run on our current machines. To be able to solve problems of realistic physical interest, a computer at least in the gigaflop range (one billion floating point operations per second) will be required by FY 1990 and in the 10 to 100 gigaflops by FY 1992. ORNL expects parallel computers of such capacity to be available in the indicated time frame from commercial vendors.

Preliminary studies of the type envisioned have already begun under support from the Director's R&D Funds (part of ORNL's Exploratory Studies Program). Pilot projects in the first two areas mentioned above (superconductors and lepton pair production) are currently being implemented by interdisciplinary teams at the Laboratory. These projects have made excellent progress in implementing parallel codes of realistic complexity on our primary existing parallel computer, a 64-processor Intel iPSC/2 hypercube. However, because this machine is limited to a peak computation rate for these problems of about 20 megaflops, full size problems have been unable to run in a reasonable amount of execution time (even modest-size problems require about a week of execution time). Plans are under way to acquire a machine of the necessary speed as soon as one becomes available commercially.

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. Several federal funding agencies, including DOE, have expressed an interest in establishing centers for intensive research in this area. The DOE-ER Applied Mathematical Sciences program is expected to request over $20 million in new funds in FY 1991 for such research. By taking this early initiative in tackling computational grand challenges, ORNL will be in an excellent position to contribute in this vital area and to be an important player in any national research program in high-performance computing.

Total budget projections for this initiative are provided in Table 4. Note that the large parallel computer expected in FY 1990 and the more massively parallel computer in FY 1992 will be purchased under a lease-to-ownership arrangement with operating funds.

Table 4. Budget projections by fiscal year for Grand Challenges in Computational Science ($ in millions)

	1988	1989	1990	1991	1992	1993	1994	1995
Operating	0.0	0.4	1.6	5.0	7.0	7.0	7.0	7.0
Capital	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2

Multifaceted Research, Development, and Demonstration Program in Hazardous Waste Management

The management of radioactive, chemical, and other hazardous wastes is receiving a great deal of national attention from both the government and the general public. Within DOE, this issue has recently been elevated to the highest levels, with emphasis on cleanup of the historic legacy of wastes at federal facilities. Also of concern are handling of current and future wastes and minimizing waste generation. The estimated costs of this undertaking are enormous, thereby accentuating the need for cost-effective, as well as environmentally safe, methods for dealing with wastes. The current capability to manage the problem is limited because technologies required to identify and manage many waste issues are incomplete and sometimes unexplored.

Using established technologies will mandate a large federal investment to clean up federal facilities; therefore, performing research and development is necessary to understand the risks quantitatively so that they can be addressed from a strong scientific base. Research can also help the federal waste cleanup program in establishing priorities. The purpose of this proposed initiative at ORNL is to research, develop, and demonstrate advanced technologies that will significantly reduce the cost of waste management while meeting current and future disposal requirements in a manner acceptable to the public. Although much of the research will be of an applied nature, it is expected that significant basic research will also be required. This program will develop technologies that can (1) better identify and characterize the hazard, both the contaminant and the site, and technologies that can (2) remediate the contaminated sites, handle wastes currently generated, and identify process improvements to mitigate further waste generation. Both of these program components are described below. This program will provide the technology research and the development and demonstration interface with the environmental restoration programs.

One component of the multifaceted program will be 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, more useful tools need to be developed to help respond to compliance requirements at minimal cost, including modeling of hydrologic systems; the development of advanced field measurement and sensing techniques; and improved methods for data collection, analysis, management, and display. In all cases, minimizing costs will be an essential criterion for the R&D objectives. Some specific examples of research that fall into this category are

- biomonitoring—using natural biological indicators and biomarkers to assess the existing health of systems and the ecological impact and effectiveness of remediation measures;
- migration of contaminants in water and soil—understanding the factors that influence contaminant migration to better predict what, where, and how to treat contaminants;

- chemistry of organic and inorganic waste forms in water and soils—achieving predictive understanding of contaminant behavior and response to remediation techniques and improved and cheaper analytical techniques in situ and real time;
- site characterization—developing field-oriented methods that allow both sites and contamination extent to be characterized with minimal cost and health/safety impact;
- health effects—understanding the toxicity and transport mechanisms of contaminants to assist in establishing priorities for cleanup activities and developing biological-based solutions to waste problems; and
- probabilistic risks, risk communication, cost/benefit analyses, and scaling studies—linking research solutions to real-life, real-time problems and objectively establishing remedial action priorities and estimating and portraying risks so that an informed public can participate in decision making.

The second component of the waste management research, development, and demonstration initiative involves assessment of existing waste management methods (Fig. 7) and evaluation, development, and demonstration of new potential technologies for waste treatment. Some of these potential technologies may currently be in

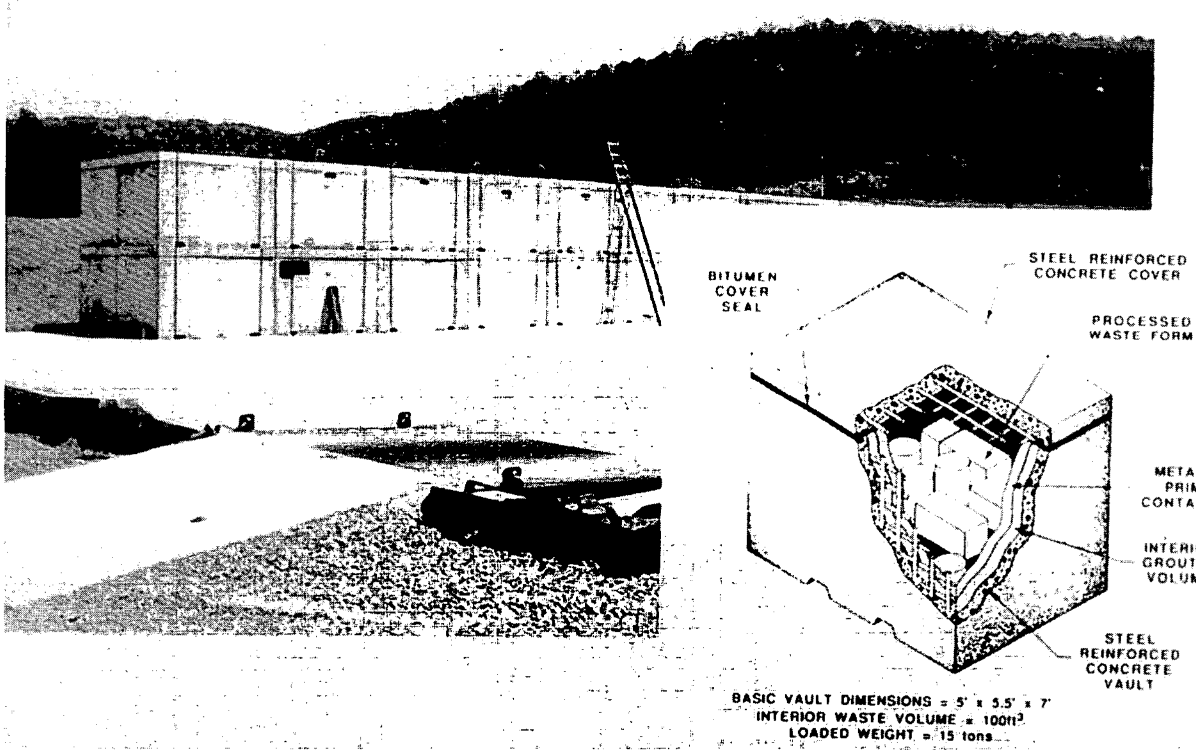


Fig. 7. The French have developed a unique process for long-term storage and disposal of low-level waste where the waste is placed in concrete casks, sealed with concrete, and stacked on monitored, controlled concrete pads. When the pad is full, the casks are covered with an engineered cap for above-ground disposal. Oak Ridge has refined the French concept and, with the regulatory support of EPA and the state of Tennessee, is demonstrating this concept.

use in other industries, but they have not been considered for applicability to waste management. These technologies need to address all three frontiers of 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. Among the technologies that will be evaluated and developed for use in waste management are

- bioremediation/biotechnology—microorganisms can fix, degrade, detoxify, or accumulate organic and selected inorganic species in situ or in process;
- artificial intelligence and robotics—autonomous intelligent robots can perform routine operations with hazardous materials that would pose significant health risks to humans;
- waste minimization—wastes can be reduced in volume and/or toxicity through techniques ranging from fundamental chemical reactions to engineering and process redesign concepts;
- in situ stabilization—wastes can be treated in situ to reduce their detrimental impact on the environment; and
- advanced separations technologies—waste can be concentrated in relatively small volumes and managed more effectively.

While the technologies listed above are currently developed to some extent, 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.

The nature and visibility of waste management issues indicate that a very aggressive program and growth rate are necessary and appropriate. The proposed incremental budget for this initiative is shown in Table 5.

Modernization of the Isotopes Program

DOE's decision to establish an Isotopes Program under the Assistant Secretary for Nuclear Energy represents a major commitment to ensuring the supply of stable and radioactive isotopes as a nationally important mission for DOE. As a lead organization for the DOE Isotopes Program, ORNL must initiate a program to modernize isotope-related facilities and equipment and to develop related management systems that are responsive to current and future needs for controlling technical operations and business activities. These steps are necessary to ensure that critical target irradiation, isotope processing, and isotope distribution activities can be safely and efficiently executed. This modernization initiative covers three target areas: (1) ensuring safety of existing operations through an extensive facility, process, and procedure upgrade program; (2) identifying, researching, and developing new applications for isotopes; and (3) integrating

Table 5. Budget request by fiscal year for the ORNL Multifaceted Research, Development, and Demonstration Program in Hazardous Waste Management ($ in millions)

	1990	1991	1992	1993	1994	1995
Operating	8	15	25	40	50	55
Capital	1	2	4	5	5	5

process improvements into existing operations to improve efficiency and produce special isotopes.

Upgrade of Existing Program

The first priority of the modernization initiative is to evaluate, reequip, and modernize the radioisotope processing capabilities at ORNL so that we can continue to process and supply radioisotopes in an acceptably safe manner. Improvements will include both facility modernization and the upgrading of safety management, training, and quality assurance. Operation of processing facilities at ORNL to meet modern environmental, health, and safety requirements will require long-term funding commitments. Nearly all the facilities are more than 30 years old and were not designed to current standards. A major investment initiative, starting in FY 1990 and continuing for several years, will be required to maintain processing capability and to comply with current environmental, health, and safety requirements. This investment requires additional operating budget to conduct operations in compliance with the new DOE safety policy and orders; unless fiscal policy changes are made, these additional operating costs will affect the isotope pricing structure because current policy mandates that the budget must match the revenues.

Preliminary estimates for specific capital improvements are shown in Table 6. Line-item funding for design and construction activities is needed for (1) a new liquid low-level waste collection and transfer system for the Isotopes Circle Facilities at ORNL and (2) an Isotopes Processing Complex (IPC), which is a major facilities consolidation and construction project. Options being considered are modernization of existing facilities, consolidation in a newer existing facility, and construction of a completely new facility. Although these preliminary estimates represent a large financial commitment, the program fulfills the country's needs for special isotopes while recovering the costs of operations. In fact, since its inception, the ORNL Isotopes Program has generated about $48 million of

Table 6. Budget request by fiscal year for Modernization of the Isotopes Program ($ in millions)

	1989	1990	1991	1992	1993	1994	1995
Isotopes Program							
Operations	13.6	13.6	13.6	13.6	13.6	13.6	13.6
Capital		1.4	0.5	0.5	0.5	0.5	0.5
Facility compliance							
Operating		6.0	4.0	2.5	2.5	2.5	2.5
Capital		1.9	1.7	0.5	0.5	0.5	0.5
PSP operating	0.15	0.2	2.5	3.5	4.3	6.5	6.5
LLLW-CAT line item							
Operating			0.6	0.2	0.2	0.2	0.2
Capital				7.0	16.1	16.0	3.4
IPC construction line item							12.0

revenue over and above the actual cost of operations. This figure is much higher if expressed in terms of 1988 dollars.

Expanded Applications for Radioisotopes

As part of its role in the Isotopes Program, ORNL perceives the need to continuously evolve and transfer to the private sector advanced isotope-related technologies. These include both isotope separation and processing technologies and technologies based on newly discovered uses for isotopes. Promising areas for these latter technologies include diagnosis and treatment of cancer, evaluation of the structural integrity of aircraft, the detection of explosives in airport environments, and the evaluation of transport and fate phenomena for environmental pollutants. A major market opportunity exists for short-lived fission products. ORNL will add new product lines to the Isotopes Program through a research, development, and evaluation program activity designed to develop new applications.

Enhancement of Isotope Separation Capabilities

An important new isotope separation capability exists in the Plasma Separation Process (PSP). PSP is a process for separating large quantities (>10 kg/year) of isotopes of most metallic elements (Fig. 8). Developed for DOE by TRW, Inc., PSP has demonstrated production

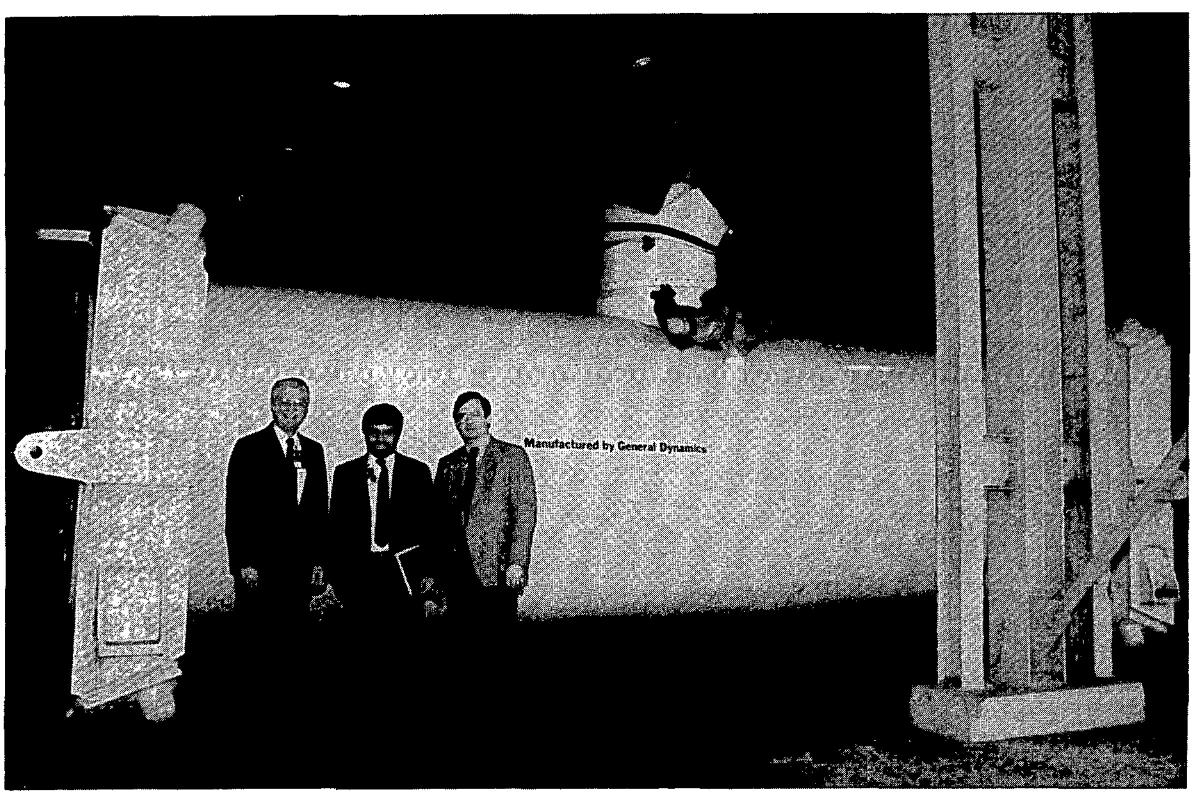


Fig. 8. Shown here is the 2-T superconducting magnet that is used in the PSP isotope separation process. This device is the largest homogeneous-field magnet in existence.

rates for separated isotopes that are two orders of magnitude greater than existing calutron facilities at unit production costs that are lower by factors of 5 to 20. During 1988 and 1989, the responsibility for the PSP program was shifted from TRW, Inc., to ORNL, and the existing separator facilities were dismantled and shipped to the Oak Ridge Gaseous Diffusion Plant for storage. ORNL has conducted an assessment of PSP isotope applications and determined that several major isotope needs can be met only by reassembly and restart of the PSP system. The major applications include (1) nickel isotopes for beam guides in research reactors [such as the Advanced Neutron Source (ANS)] that can increase the neutron flux at some research instruments by factors of 3 to 9; (2) palladium isotopes used for radiological seeds for treatment of fast-growing prostate cancer; and (3) rare-earth isotopes that can be used as burnable poisons to enhance the economics and safety of light-water reactors. The proposed reassembly and start-up of the PSP system is estimated to cost about $10 million, which would lead to revenue-producing production operations in FY 1994. The PSP system would represent a complement to calutron and gas centrifuge systems currently available at ORNL and would become a cornerstone in an integrated isotope separations complex at ORNL.

Life Sciences Complex

A critical problem requiring immediate resolution is the aging of the energy-inefficient facilities used by the Biology Division at the Y-12 Plant. In addition to the marginal service and utility capacities of the buildings, the cost of utilities was consuming almost 25% of the total research operating budget. This high cost of conducting research was adversely affecting ORNL's competitiveness in basic biological research and placed the future of this program in jeopardy. In FY 1987, the Biology Division staff began an interim program of reducing costs by eliminating facilities and consolidating research activities. Biological research projects formerly located in the largest building (9207) were moved into two smaller buildings nearby. The long-range plan is to move the major research components of the Biology Division from the Y-12 Plant to specially designed biological research facilities located in the Life Sciences Complex at the west end of ORNL. A long-term solution is the construction of new facilities at this complex.

The obvious programmatic advantage to relocating the Biology Division to the existing Life Sciences Complex at ORNL is that the close proximity to the biomedical and environmental sciences divisions would provide an opportunity to share resources and thus enhance collaborative research efforts. In addition, a major problem of security access can be eliminated, because noncitizens can enter ORNL's west end, where the Life Sciences Complex is located, more easily than the Y-12 Plant.

Also, the planned expansion of defense-related activities at Y-12 may have adverse impacts on the Biology Division.

Many essential facilities for modern biological research (e.g., structural biology) are located at ORNL. These facilities include the National Center for Small-Angle Scattering Research, the Bioprocessing Research Facility, and the planned ANS.

Budget Requirements

Conceptual design has already been completed for the proposed Molecular Genetics Laboratory as an FY 1992 line-item construction project. The proposed laboratory will provide the resources required for advanced-level molecular genetics research. The building will be of cost-effective modular design, with one-time engineering and design costs, and additions will be modular units of the same design. In addition to the requested $36.4 million in KP program construction, investments are planned of ~$1 million in program overhead to support projects, ~$5 million in GPP projects in the Life Sciences Complex, and ~$18 million in general purpose facilities located in the complex.

Table 7 outlines a 5-year plan for proposed spending for the development of the Life Sciences Complex (Fig. 9).

Table 7. Life Sciences Complex development[a]
($ in million)

Project	Fiscal year 1989	1990	1991	1992	1993	1994	1995	Total estimated cost
	Operating	Operating/ Capital	Operating/ Capital	Operating/ Capital	Operating/ Capital	Operating/ Capital	Operating/ Capital	
Program KP								
Molecular Genetics Lab		0/0	0/0	0/1.5	0/10.8	0/0	0/0	12.3
Life Sciences Lab		0/0	0/0	0.3[a]/0	0/1.4	0/9.9	0/0	11.6
Life Sciences Lab		0/0	0/0	0/0	0/0	0.35[a]/0	0/1.6	12.5[b]
Total								36.4
Program AT (GPP)								
Data analysis facility	0.06	0/1.2						1.2
West-end utility extension	0.04	0/0	0/0.3					0.3
West roads and parking improvements		0.04/0	0/0.4					0.4
Life Sciences office building			0.07/0	0/1.2				1.2
Geosciences Research Lab				0.07/0	0/1.2			1.2
West-area infrastructure extension					0.04/0	0/0.6		0.6
Total								4.9
Program KG-01 (Capital costs only)								
Steam system upgrade				1.1	5.15	0.75		7.0
ALARA support facility						1.5	5.0	11.0[b]
Total								18.0

[a]If these facilities are clones as planned, operating costs will be less.
[b]Includes funding for remaining out-years.

Energy Technologies for Developing Nations

The energy choices made by developing nations 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. This means at least three things to the United States. Resulting energy use by developing nations, including fossil fuels, is likely to contribute significantly to the global build-up of greenhouse and ozone depleting gases in the atmosphere. Figure 10 shows that 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. Finally, 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 R&D can be an important part of the U.S. response to all three of these

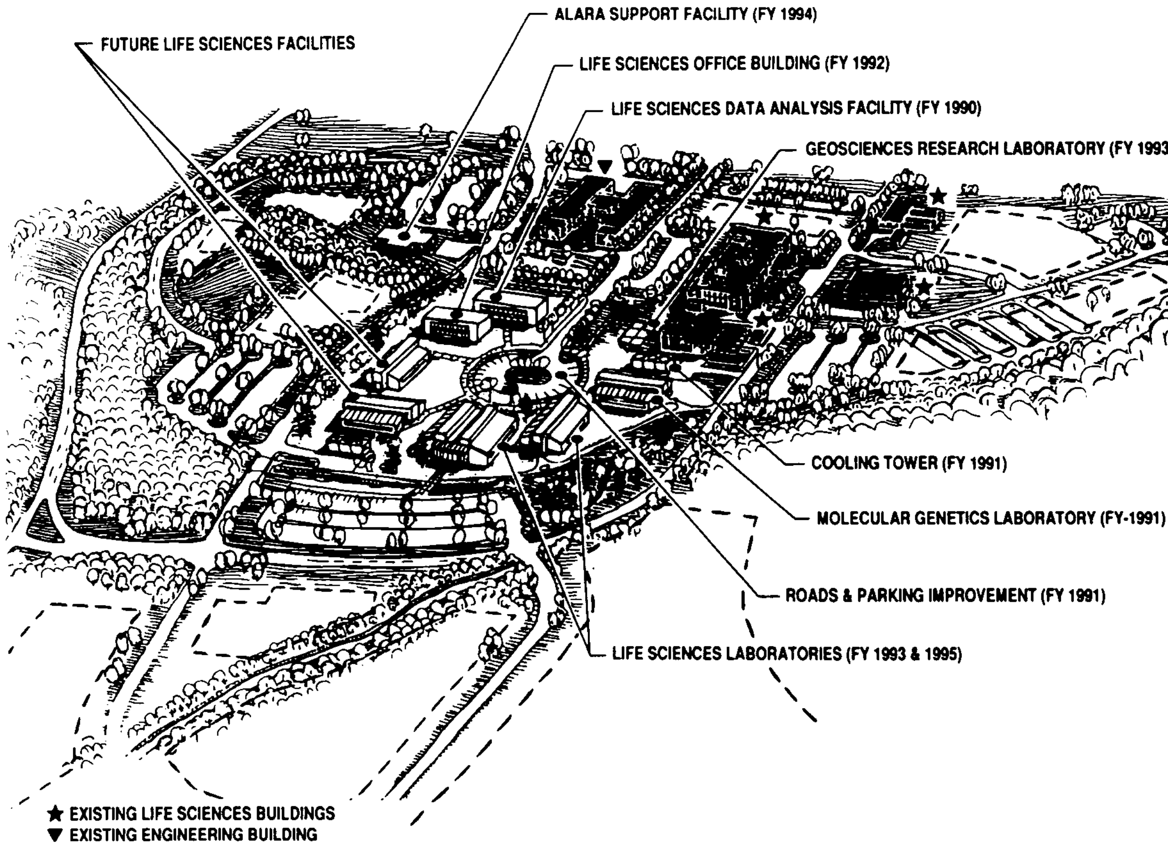


Fig. 9. Proposed Life Sciences Complex.

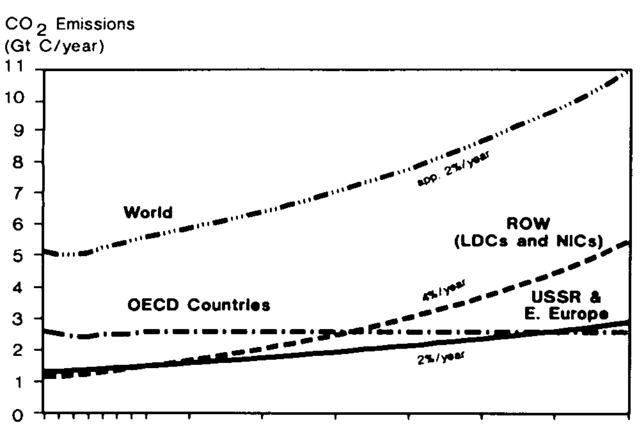


Fig. 10. Extrapolation of CO_2 emissions based on the average growth rates for the period 1977 to 1987. The rest of the world (ROW) includes developing countries and newly industrialized countries (NICs). About two-thirds of the CO_2 emissions from ROW countries in 1987 were from the developing countries, including China and India.

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 United States' share of energy technology markets improved.

DOE and other federal agencies have already begun exploring these opportunities. For example, 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. DOE recently proposed to extend CORECT to include an Integrated Electric Utility Program (IEUP) to assist developing countries with electricity system expansion planning, and

DOE's Office of Conservation has called for the creation of a parallel Committee on Energy Efficiency in Commerce and Trade. Other activities are being explored as well. For instance, DOE's Climate Issue Responses Group has suggested an increasing role for DOE relative to the global warming issue, and DOE's Office of International Affairs is developing a study on energy cooperation in the western hemisphere, as directed by the 1988 Energy Policy Act. DOE's Clean Coal Program has also shown a strong interest in developing country markets for improved, more efficient U.S. technologies for coal use.

In 1989, as part of the development of the U.S. National Energy Strategy (NES), a background paper, "Energy Technology for Developing Countries," was commissioned by DOE from the national laboratories, including ORNL.

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 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 energy needs for developing country economic growth while at the same time reducing stress on the global environment and world oil market—and improving the U.S. trade balance—through technology development, improvement, and adaptation.

The new ORNL initiative will consist of two parallel approaches, one focused on key nations or regions of the world and the other on specific technologies:

- *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, 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., China, India, and Brazil), their importance as potential markets for U.S. energy technologies (e.g., Southeast Asia), and their importance in meeting development needs (e.g., the Sahel) or U.S. policy objectives (e.g., 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 now to combine its developing country experience with DOE program priorities to identify energy technology R&D directions 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 sources of ideas for the U.S. private sector. 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.
- *Comprehensive energy information system*
  ORNL will also 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.

ORNL already has significant technical assistance activities under way for AID. These include an energy policy development project funded at about $1 million per year and a renewable energy project at about $600,000 annually. Policy development includes power system planning and efficiency improvement, environmental management issues, energy price reform, and institution building. The renewable energy project focuses on energy options for rural areas, including the evaluation of renewable energy project potentials around the world. The work of these projects involves people from several divisions, including Energy, Environmental Sciences, Engineering Technology, and other divisions.

In addition, ORNL has for several years been supported at a lower level by DOE for work related to energy technologies for developing nations. Funding in the range of from $100,000 to $150,000 per year has included sponsorship by Conservation and Renewable Energy (for assistance to CORECT), Fossil Energy, and International Affairs. For example, a pilot study is being conducted for DOE's Office of Photovoltaic Technology to test an innovative method for financing small photovoltaic/battery systems for homes remote from the central electric grid. If it works, such an approach should be equally applicable to small, decentralized investments to improve the efficiency of energy use. We expect this project to lead to a broader role for ORNL as part of the new Integrated Electric Utility Program. In addition, the possibility of establishing a Design Assistance Center at ORNL for end-use efficiency improving technologies is being discussed as part of IEUP.

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.
- DOE
  The background paper for the NES, "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. Otherwise, principal support is likely to come first from 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 8 indicates the budget proposed for the ORNL initiative in this subject area.

Other New Initiatives

Additional new initiatives, (1) Center for Mathematical Environmental Modeling, (2) Structural Biology, (3) Human Health Risk Analysis, and (4) Subsurface Research, are discussed in the Scientific and Technical Programs section, Office of Energy Research.

Table 8. 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
WFO (AID)	0.4	0.5	0.8	1.0	1.0	1.0	1.0
DOE	0.1	0.5	1.2	3.0	7.0	8.0	9.0
Total	0.5	1.0	2.0	4.0	8.0	9.0	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.

Continuing Initiatives

Advanced Neutron Source

The ANS Project will provide a large, steady-state neutron source to support research programs that broaden the body of knowledge on which today's applied technologies rest and to allow research on new technologies that will be important in the coming decades (Fig. 11).

A portion of the mission needs of the ANS are currently provided by the High Flux Isotope Reactor (HFIR) and the High Flux Beam Reactor; however, these existing facilities are approximately 20 years old, and they cannot be modified to meet future neutron research needs effectively. The ANS will be able to replace both of the existing reactors while greatly enhancing the research capabilities in neutron scattering and maintaining or improving the capabilities for special isotope production (such as californium), for materials irradiation studies, for neutron activation analysis, and for nuclear physics.

Specific technical objectives for the ANS are established by the National Steering Committee for an Advanced Neutron Source, which is comprised of more than 30 representatives from DOE laboratories, the National Institute for Standards and Technology, universities, and industry. 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 these performance criteria, it is necessary to design and construct a physically small, high-specific-power reactor with a nominal thermal output of 300 to 350 MW. The project schedule indicates reactor startup would occur late in FY 1998, which approximately coincides with the estimated end-of-useful-life for the existing reactors. The ANS 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 requirements for comparable licensed facilities. Preliminary estimates for the total project construction-phase cost are in the range of from $400 to $600 million (FY 1989). Detailed budget projections are included in Table 9.

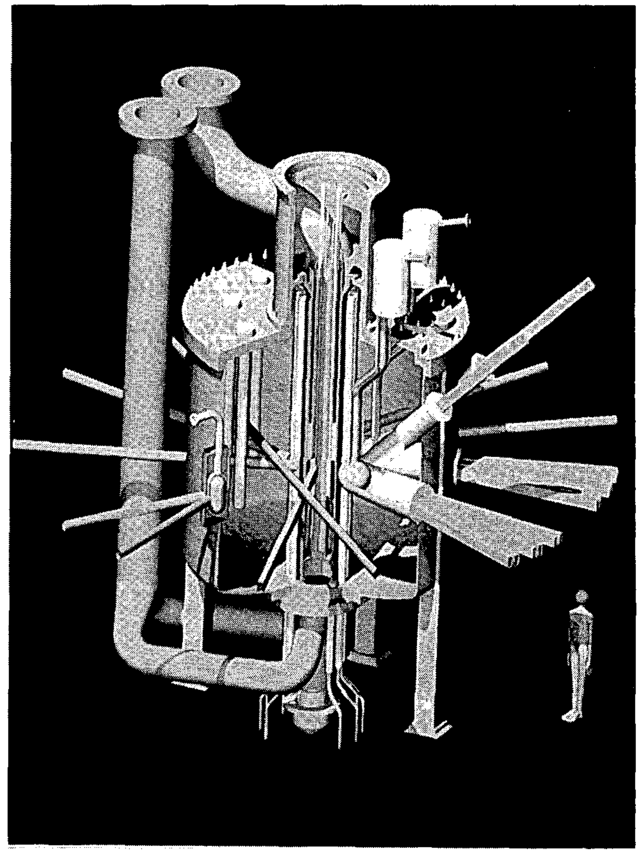


Fig. 11. Depiction of the ANS reactor core assembly.

The ANS Project has been supported through the DOE Office of Basic Energy Sciences (BES). The project recently initiated a conceptual design, with a final conceptual design report scheduled for completion in mid-FY 1992. During the past year, a conceptual design-phase reference core was defined and documented, and project teams were established for the reactor systems, experiment systems, and the balance-of-plant conceptual design activities.

Design and construction of a reactor that will meet all of the performance criteria are considered feasible. However, remaining uncertainties with respect to definitive regulatory and licensing

Table 9. Budget projections (BA) for the planning period by fiscal year for the Advanced Neutron Source ($ in millions)

	1988	1989	1990	1991	1992	1993	1994	1995
Operating funds	2.7	7.4	8.7	7.2	7.8	6.4	5.8	5.8
Capital equipment		0.4	0.8	1.1	0.6	0.7	2.7	0.7
Design-only line item				39.4	40.7	32.0		
Construction line item							TBD[a]	TBD
Total	2.7	7.8	9.5	47.7	49.1	39.1	TBD	TBD

[a]To be determined.

requirements, specific site selection, and detailed scientific requirements prompt a phased approach to the project. The ANS Project is structured as a 3-year design-only phase (FY 1991–1993), followed by a design completion and construction phase (FY 1994–1998). This provides a means to preserve the FY 1998 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.

Heavy-Ion Storage Ring for Atomic Physics

The Heavy-Ion Storage Ring for Atomic Physics (HISTRAP), a 2-T-m synchrotron/cooler/storage ring, has been an ORNL initiative for several years. The study of 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 proposed HISTRAP facility will be associated with the Holifield Heavy Ion Research Facility (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. To prepare for construction of the HISTRAP, nearly $900,000 of ORNL Director's Exploratory R&D 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	Total estimated cost
7.8	6.5	4.2	18.5

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 materials development will be required before these new materials are understood and future applications realized. 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 fabricate them into conductors with high critical currents in the presence of high fields, to identify viable commercial applications, and to work closely with U.S. industry to accelerate the commercial application of these discoveries. The R&D efforts focus on four major areas: (1) synthesis, (2) characterization and analysis, (3) thin films and devices, and (4) high-current conductors.

In FY 1987, redirected funding totaling about $1.8 million facilitated research at ORNL in this rapidly progressing area. In FY 1988, about $4 million in new and redirected funds supported this research initiative.

ORNL has established close interactions with Los Alamos National Laboratory (LANL) and Lawrence Berkeley Laboratory (LBL). During 1988, ORNL was named one of three DOE Superconductivity Pilot Centers (SPCs). LANL and Argonne National Laboratory (ANL) have the other two pilot centers. The purpose of these pilot center projects is to enhance interactions involving the new high-temperature superconductors between national laboratories and U.S. industry and to accelerate the transfer of technology to the private sector by streamlining the business–legal interface between DOE and U.S. industry. Funding for high-temperature-superconductor research at ORNL grew to about $5.5 million in FY 1989, including $1.5 million to support the DOE-SPC. This research area needs to grow substantially because of the long-range potential for applications of high-temperature-superconducting materials, which can significantly increase our energy efficiency and international competitiveness (Table 11).

Microwave Sintering of Ceramics

Microwave sintering has unique attributes and the potential to be developed as a new technique for controlling microstructure to improve the properties of advanced ceramics. For example, advanced ceramics are important to the development of a motor vehicle engine that can operate at higher temperatures with greater energy efficiency. Because microwave radiation penetrates most ceramics, uniform volumetric heating is

Table 11. Budget projections by fiscal year for research and development and the High-Temperature Superconductor Pilot Center (includes both new and redirected funds; $ in millions)

	1988	1989	1990	1991	1992	1993	1994	1995
Research and development	4.0	4.0	4.5	5.0	5.0	5.0	5.0	5.0
Superconductivity Pilot Center (SPC)[a]	0	1.5	3.0	5.0	10.0	12.0	12.0	12.0

[a]SPC funds do not include industrial partner costs.

possible, and thermal gradients, which are produced during conventional sintering, can be minimized. By eliminating temperature gradients, it is possible to reduce internal stresses, which contribute to cracking of parts during sintering, and to create a more uniform microstructure, which may lead to improved mechanical properties and reliability (Fig. 12).

With funds from the ORNL Director's R&D Fund, an interdisciplinary team at ORNL built and operated a novel microwave furnace in FY 1987. Experiments were performed to characterize the sintering behavior of aluminum oxide using 28-GHz radiation as energy input. It was discovered that the apparent activation energy for sintering of alumina in this field was only

Fig. 12. Striking examples of good and bad microwave-sintered zirconia medallions. The good piece was fired in the ORNL 28-GHz microwave oven for 1 h at 1150°C. During sintering of the bad piece, a hot spot developed that generated differential shrinkage, resulting in large thermal stresses. The stresses produced the final cracking of the part during sintering.

170 kJ/mol, compared to 575 kJ/mol for conventional heating. The alumina compacts were densified at temperatures 400°C lower than those required for comparable densities with conventional heating. With lower-temperature processing it is possible to reduce grain growth, vaporization, and interactions between phases, which are often significant in the fabrication of advanced ceramics.

There are a number of important implications from these results. Lower temperatures offer the potential for avoiding undesirable chemical effects such as thermal decomposition. Lower temperatures also offer the possibility of new material combinations such as semiconductor packages. The uniform heating may lead to more rapid production cycle times. In addition, the ability to selectively heat mixtures will make possible new microstructures that are otherwise unattainable.

Our results at both 28 GHz and 2.45 GHz show that microwave processing could produce a competitive advantage in ceramic manufacturing. The literature shows that other countries are already working to exploit microwave technology in many segments of their respective materials industries. Initial interest has been shown by several major ceramic manufacturers in this country as well.

Initial funding in FY 1986 and FY 1987 was from the ORNL Exploratory Studies Program. The program was augmented in FY 1988 and FY 1989 by funding from Conservation and Renewable Energy, Fossil Energy, and Defense Programs. Currently funded activities include

- a theory of microwave/materials interactions, confirmed by experiment, to explain the mechanisms of coupling, the enhancement of diffusion, and the roles of defects and interfaces;
- diagnostic tools, instrumentation, and techniques for the process control of microwave sintering;
- development of a process for microwave sintering or reaction bonding of silicon nitride that will accelerate densification, yield high density with much lower levels of sintering aids, and lower the sintering temperature with attendant improvement to microstructure;
- development of a zirconia-toughened alumina with improved strength, fracture toughness, and reliability;
- development of a fine-grained silicon carbide with higher strength and, perhaps, better reliability (Weibull modulus);
- development of yttrium-barium-copper oxide ceramics with microstructure modifications that may lead to improved electrical properties in high-temperature superconductors;
- development of a process for producing high-density lithium hydride; and
- sintering of zirconia and other oxides proposed for use as electrodes in solid oxide fuel cells.

Anticipated direct DOE support plus additional needed support are indicated in Table 12. As shown in the table, substantial

Table 12. Budget projections by fiscal year for Microwave Sintering of Ceramics ($ in millions)

	1989	1990	1991	1992	1993	1994	1995
Operating							
Expected DOE funds[a]	1.7	1.4	1.4	1.4	1.4	1.5	1.0
Other		0.3	0.5	0.7	1.0	1.6	1.0
Capital							
Expected DOE funds[a]	0.3						
Other				1.5			

[a]Included in resource projections. Funding is from the Office of Coal Technology, the Office of Energy Utilization Research, the Office of Transportation Systems, and the Office of Defense Programs.

additional research support will be needed to provide the technology for the U.S. ceramics industry to take a leadership position in this area. Support is being sought through continuing contacts with industry, several parts of DOE, and other government agencies.

Global Environmental Sciences

As a result of current concerns over global warming [i.e., the "greenhouse effect" (Fig. 13)], ozone depletion, reduction in biodiversity, deforestation, and other global-scale environmental issues, ORNL initiated a planning phase in early FY 1989 for the establishment of a Center for Global Environmental Studies. This planning phase included an analysis of national and international agency and governmental involvement, a definition of global environmental issues, and the development of a strategy for an ORNL role.

The new Center for Global Environmental Studies was dedicated on July 13, 1989. The dedication was marked by presentations to Laboratory staff and to participants of the 1989 DOE High School Honors Program in Environmental Sciences. The center is organized around five major themes (Fig. 14), including a central focus of global systems analysis, supported by research and analysis in data systems; measurement science and instrumentation; policy, energy, and human systems analysis; and large-scale environmental studies. The center is housed

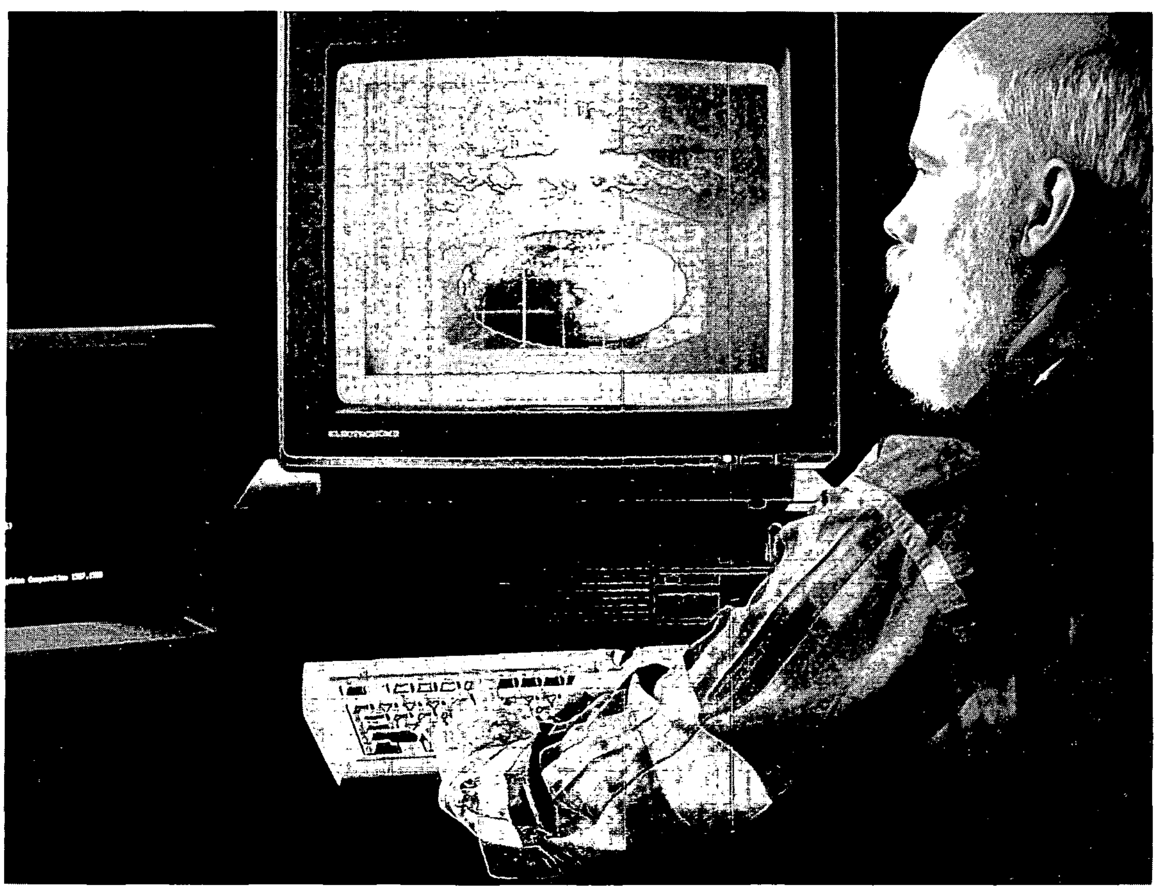


Fig. 13. Michael Farrell of the Environmental Sciences Division at ORNL examines a computer image of global warming as part of his research on the "greenhouse effect" and the possible worldwide effects of increasing atmospheric levels of carbon dioxide.

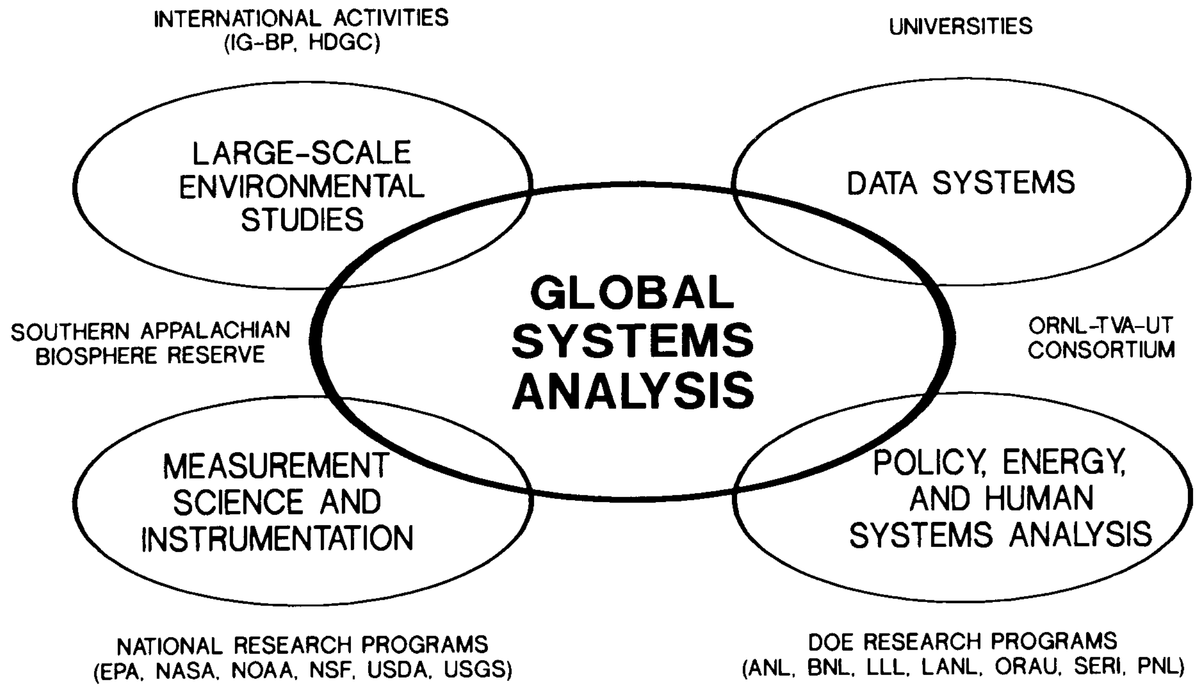


Fig. 14. The ORNL Center for Global Environmental Studies is organized around five major themes, the central one being Global Systems Analysis.

in ORNL's Environmental Sciences Division (ESD) and involves numerous staff members from other ORNL divisions and collaborating universities. It is a focal point for ORNL's existing scientific leadership in biogeochemical cycling, pollutant effects, mathematical modeling, information systems, project management, measurement science, and policy analysis.

ESD conducts research on the carbon cycle and maintains the Carbon Dioxide Information Analysis Center for the Carbon Dioxide Research Program of the Office of Health and Environmental Research (OHER). ESD is actively involved in relating ecological process research on the DOE National Environmental Research Parks to global environmental issues. ORNL is supporting OHER in developing an initiative using ecological theory, mathematical modeling, and empirical studies on the parks to address regional- and global-level issues. We are also working with the other six National Environmental Research Parks to facilitate networking and electronic data exchange. The Laboratory's Energy Division is supporting the Assistant Secretary for Environment, Safety, and Health's Office of Environmental Analysis in developing policy options for mitigating global warming. Additionally, both the Energy Division and ESD are assisting AID in evaluation and analysis of energy options and environmental concerns in developing nations, with emphasis on renewable technologies.

ORNL is committed to supporting the development of a global scientific initiative for DOE and is assisting in the planning necessary to identify the unique scientific contribution that DOE can offer the Intergovernmental Panel on Climate Change, the national Committee on Earth Sciences effort, and the development of interinstitutional mechanisms for coordination with other agencies.

Ongoing ORNL research in several areas will be continued and expanded with university and other laboratory collaborators:

- global biogeochemical cycles;
- global data-base networking;

- advanced measurement systems;
- modeling of hierarchical-, temporal-, and spatial-scale interfaces;
- research on the linkages of environmental processes between atmosphere, land, and surface waters at the landscape level;
- impacts of climate change on regional resources; and
- policy, energy, and human systems analysis.

This initiative builds upon research currently supported through the ORNL Director's R&D Fund, the DOE Carbon Dioxide Program, and the research sponsored by AID and the National Science Foundation (NSF). The uniqueness of ORNL's contribution lies in its interdisciplinary research approach, experience, and leadership capability to develop and support interinstitutional projects to address large-scale and complex global environmental problems (Table 13).

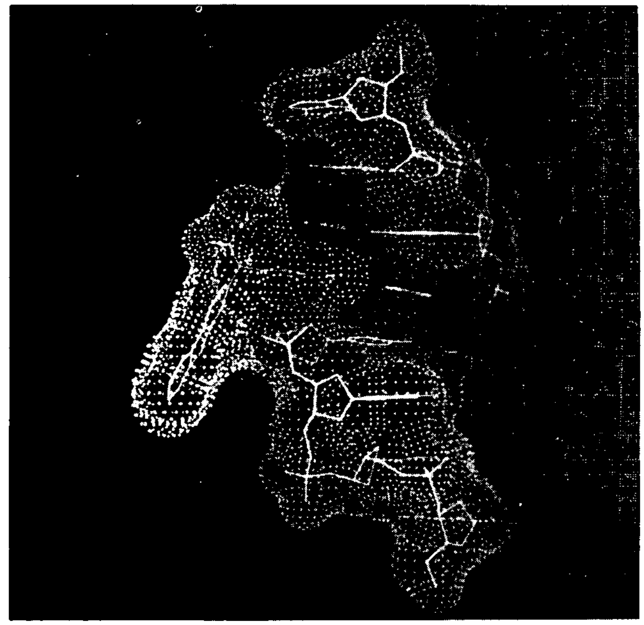


Fig. 15. Using a supercomputer, Brian Hingerty in Health and Safety Research Division has helped develop this molecular model of a carcinogenic adduct attached to 8 base pairs of DNA duplex.

Genome Mapping and Sequencing

An expanding initiative entails mapping of regions of the mouse genome that are homologous to the human genome and developing new or improved methods for deoxyribonucleic acid (DNA) sequencing. Our multidisciplinary research capabilities and experience will allow us to make significant contributions to both the National Institutes of Health genome program and DOE's human genome initiative (Fig. 15).

The major objective with respect to mapping is to explore the structural and functional characteristics of the mammalian genome by use of experimental molecular genetics. Experimental plans include (1) development of complete molecular maps and refined functional maps of several specific regions of the mouse genome; (2) analysis of the molecular structure and effects of heritable, agent-induced mutations; (3) creation of molecularly tagged mutations throughout the murine genome by insertional-mutagenesis techniques; (4) utilization of mutagenesis protocols that generate deletion mutations to expand the genomic regions accessible to molecular-structure analyses; and (5) application of mutagenesis techniques to screen for models of important

Table 13. Budget projections by fiscal year for Global Environmental Sciences[a] ($ in millions)

	1989	1990	1991	1992	1993	1994	1995
Operational	5.0	4.0	6.0	8.0	10.0	10.0	10.0
Capital	0.05	0.075	0.1	0.1	0.1	0.1	0.1

[a]Includes university subcontracts.

human genetic disorders that can then be analyzed molecularly.

In parallel with these proposed studies are ongoing activities designed to provide information on the mechanisms of induction of point mutations and chromosome alterations, with particular attention to the induction and consequences of nonrandom alterations.

A noteworthy feature of this initiative is the integration of 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, including the early events that lead to mutation-associated abnormal phenotypes. Structure-function analyses of specific murine genomic regions will also facilitate characterization of homologous regions of the human genome.

We are complementing the mapping activities 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 and is currently concentrating 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. Detection and quantification of the stable isotope will employ resonance ionization spectroscopy (RIS), a method that is extremely sensitive and specific. Sputter initiated RIS will be tested because it is the most highly developed strategy of RIS. New chemistry will be developed to attach various metals to DNA; metals that include several different stable isotopes are desirable because a mass spectrometer is used as the RIS detector and each isotope thus provides a unique label. Future efforts will involve the application of these same methodologies to replace many of the radioisotope procedures that are currently being used in most molecular biology laboratories.

In addition to the above effort, several other projects in genome technology development are being pursued in the Health and Safety Research, Instrumentation and Controls, and Solid State divisions. These include the following:

1. The development of faster and more accurate techniques for DNA sequence detection based on synchronous fluorescence, room-temperature phosphorescence, and enhanced Raman spectroscopy. This project will lead to the development of an integrated multiplexed system that combines the advanced spectrochemical schemes into a single instrument.
2. The development of filmless electronic autofluorography approaches to mapping and to the Church-Gilbert sequencing method.
3. The development of a gel-less DNA sequence analyzer with the potential for 10^6 bases/d.
4. New chemical approaches to sequencing whose development will provide direct information on the composition of each sequence position, including that at the modified bases (this information is not currently available). The technology involves the sequential removal of the terminal deoxynucleoside from DNA and quantifying the released base within the same cycle.
5. Computer modeling on DNA sequences modified by carcinogens. The most energetically favored conformation of small DNA subunits will be determined. These will then be incorporated into larger double-stranded DNA, up to 12 base pairs, and the deformations caused by several carcinogens will be assessed by potential energy methods.
6. The organization of genomic DNA and associated nuclear proteins will be studied through detailed three-dimensional crystallographic analysis of the nucleosome core particle, several small genes, and the more complex polynucleosomal 30-nm fiber. We have solved the structure of the nucleosome core particle to a resolution of 8 Å. Current research is aimed at determining the structure to near atomic resolution (3 Å).

Budget projections for the Genome Mapping Sequence initiative are shown in Table 14.

Table 14. Budget projections by fiscal year for Genome Mapping and Sequencing ($ in millions)

1989	1990	1991	1992	1993	1994	1995
5.5	6.6	7.9	8.7	9.5	10.4	11.4

Modular High-Temperature Gas-Cooled Reactor Technology Development

Commercial gas-cooled reactors (Magnox reactors) were introduced in the United Kingdom and France in the early 1950s, and a number of them are still operating. Because of the use of an oxidizing coolant (CO_2) and the use of metal-clad fuel in the core, these reactors operate at relatively low temperatures.

The high-temperature gas-cooled reactor (HTGR) concept was introduced in the late 1950s (Fig. 16). This concept is highly advanced when compared to the Magnox reactors. The HTGR is helium cooled, and the core contains no metal. The combination of inert coolant and ceramic core allows much higher operating temperatures and thermal efficiency. Three pilot-scale HTGRs [Dragon in the United Kingdom, Peach Bottom in the United States, and the Arbeitsgemeinschaft Versuchsreaktor (AVR) in Germany] and two demonstration-scale HTGRs (Fort St. Vrain in the United States and the Thorium High-Temperature Reactor in Germany) have been built and operated. Several commercial plants were ordered by U.S. utilities in the early 1970s. A poor economic climate in the mid-1970s and escalating capital costs for nuclear plants resulted in cancellation of all these HTGR orders. The HTGR technology-development program was reduced to a maintenance level and was kept alive largely because of interest in Congress.

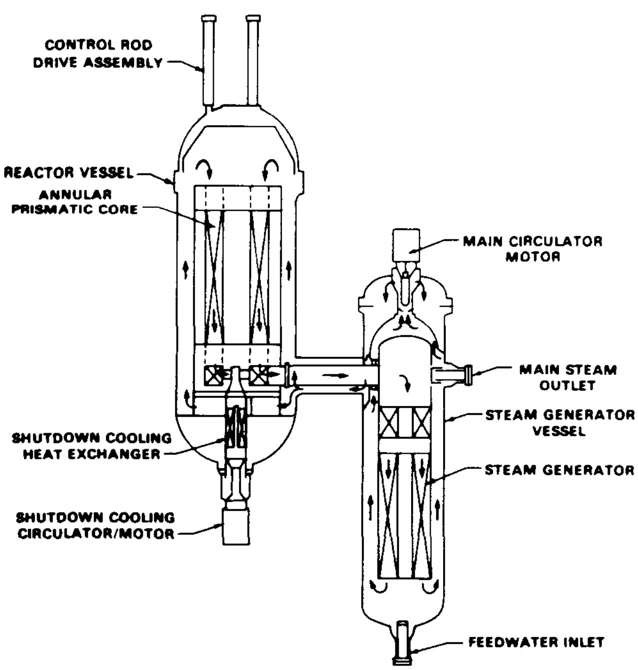


Fig. 16. Schematic drawing of the modular high-temperature gas-cooled reactor.

In recent years, the leadership within the U.S. nuclear community began to realize that fundamental changes in design concept were required if the nuclear enterprise was to continue beyond the current generation of light-water reactors (LWRs). HTGR designers refocused their efforts from the large (3000 to 4000 MWt) plants with high efficiency and high fuel use to smaller, modular plants. The modular HTGR (MHTGR) designs consist of four units, each 350 MWt (138 MWe), headered to two turbines. The design calls for location in an underground silo. Annular core configuration and small size combine to provide passive safety. Even when the primary circuit is depressurized, the decay heat from the core can be dissipated through the vessel to the ground. The maximum temperature of the fuel will not rise above 1600°C, a temperature at which it can survive without significant damage or fission product release. This feature of passive safety offers many advantages.

- It avoids the need for emergency evacuation and sheltering plans.
- It provides an enhanced degree of investment protection; a plant can restart after an "accident."
- It eliminates the need for expensive redundant active safety systems; the cost savings offset higher costs caused by the smallness of scale.

- The small core of the MHTGR can be housed in a steel pressure vessel that can be fabricated in a factory; reduction of field fabrication also provides cost benefits.

Civilian MHTGR Technology Development

ORNL's lead role in this initiative is in the area of technology development. Responsibility for MHTGR design development resides with several commercial organizations and is divided by system (e.g., Reactor Vessel and Balance of Plant). The MHTGR design team has used a "top-down" approach to design, starting with top-level regulatory and user requirements. Design features have been linked to top-level requirements through application of a disciplined functional analysis. Design selections have been based on available data and on informed assumptions for MHTGR-specific conditions where data are not yet available. It is the purpose of the technology development program to validate the assumptions and the design tools. The MHTGR technology development program at ORNL includes seven specific components:

- *Fuel performance.* Performance data on MHTGR-quality fuel (20 times better than previous HTGR fuel) will be collected by performing irradiation tests in the HFIR and other test reactors. HTGR performance models will be modified with the data from these tests, and then the performance models will be validated through a "proof" test.
- *Fission-product behavior.* The key to the claim of passive safety lies in demonstrating that fission-product retention and transport behavior have been modeled correctly. HTGR models will be updated using data from laboratory-scale experiments. The updated models will then be validated through a series of tests in a specially designed fission-product loop in the Siloe reactor in France.
- *Graphite behavior.* The core fuel-block material, reflector material, and core support structure are manufactured from graphite. Knowledge of graphite properties, including statistical variation in properties and irradiation effects, is required for design and for the probabilistic risk analysis that must be submitted as part of the licensing procedure.
- *Metal properties.* The MHTGR design includes a steel pressure vessel similar to the vessels used in LWRs. The MHTGR vessel operating temperatures and neutron environment are considerably different from those of LWRs. Therefore, an experimental program to provide irradiation-effects data is required for licensing of the MHTGR. Also, materials data for steam-generator and metallic-core internals design validation are required.
- *Safety analyses.* Validation of core physics design tools and thermal hydraulics codes and models is important to design, analysis, and safety assurance for the MHTGR. Such validations are also required for the licensing process.
- *Shielding Analysis.* The MHTGR has several unique shielding problems. First, in contrast to water- and sodium-cooled reactors, essentially no shielding is provided by the helium coolant, and "extra" shielding structures are required. Second, the low-power density of the MHTGR results in a relatively large core, thereby reducing space for shielding between the core and a vessel of reasonable size. Unique design approaches are therefore required. This task provides a capability for analysis of shielding options and validation of the design options selected.
- *International cooperation.* HTGR development in Japan, Germany, and the United Kingdom is of interest to the U.S. program. All national programs can benefit by pooling data, test facilities, and the experience of knowledgeable individuals. Fostering this international cooperation is also the responsibility of the Technology Development Program (TDP) (Fig. 17).

Costs for base technology development are estimated at $75 million. This effort may be expanded to support additional validation tests for safety and design codes. An estimated $25 million more will be needed for component testing. The

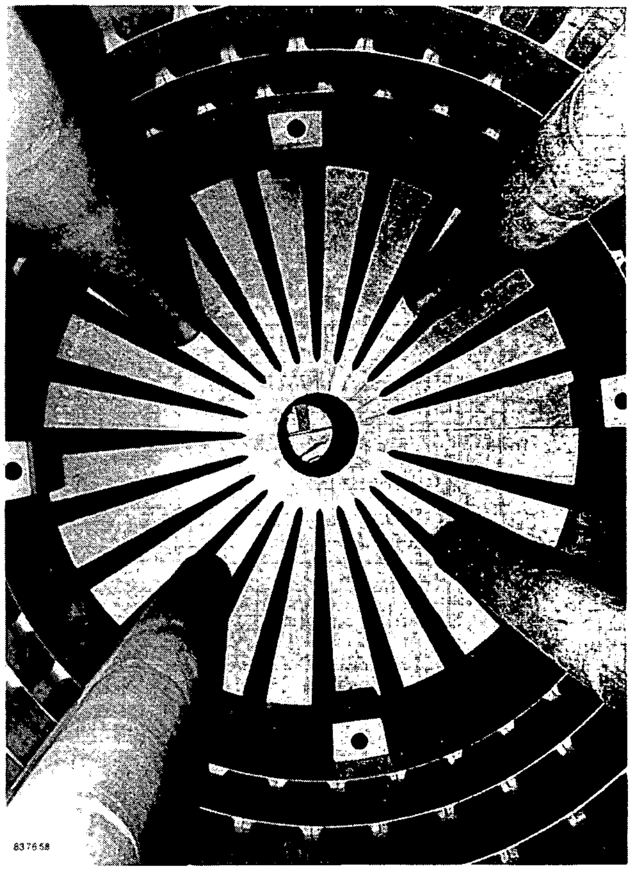


Fig. 17. The empty core of the AVR (Germany) before it was loaded with graphite pebbles containing refractory-coated particles of nuclear fuel and used in a loss-of-coolant-accident (LOCA) test. ORNL participated in this landmark LOCA test, which demonstrated the inherently safe response of this reactor to a LOCA. (Photo courtesy of AVR.)

TDP plan, which was completed in 1987, proposed completion of the technology development work in 6 years. Recent funding levels have been well below those required for the 6-year program (Table 15).

It will be difficult to establish this new nuclear option in the United States. But it is important, and we believe it is realistic, if appropriate consideration is given to public concerns for safety, economics, and waste disposal. To carry out the MHTGR technology development and validation tasks necessary to support serious consideration, this promising technology will require a vigorous new initiative over the next 6 years.

Table 15. Budget projections by fiscal year for Civilian Modular High-Temperature Gas-Cooled Reactor technology development ($ in millions)

1988	1989	1990	1991	1992	1993	1994	1995
6.0	4.2	6.3	14.8	20.1	19.3	13.4	8.2

New Production Reactor Technology Development

Following an extensive study of reactor technologies for weapons-materials production, DOE announced in August 1988 that it would support the construction of a heavy-water reactor (HWR) at Savannah River, South Carolina, and a four-module HTGR at Idaho Falls, Idaho. These New Production Reactors (NPRs) are needed to replace the aging production facilities at Savannah River (all reactors currently shut down for environmental and safety reasons) and the N-Reactor (in cold standby) at Hanford, Washington.

The HWR was selected as one of the NPR concepts on the basis of the extensive (over 35 years) operating experience at Savannah River. The expertise and experience accumulated during this period represents a reliable resource for the HWR-NPR program. To assure diversity and independence of weapons-materials supply, the MHTGR was chosen as the second NPR system. Other advantages of the MHTGR are described above.

The new climate in which weapon facilities must operate (i.e., with much increased emphasis on health, safety, and the environment) demands greater attention to all aspects of technology and quality. To this end, detailed 5-year technology development plans were very recently prepared for both NPR concepts. Input to these plans was provided by ANL, the Brookhaven National Laboratory (BNL), the Idaho National Engineering Laboratory (INEL), the Energy Technology Engineering Center (ETEC), LANL, the Lawrence Livermore National Laboratory (LLNL), ORNL, Science Applications

International Corporation, Sandia National Laboratories (SNL), and the Westinghouse Savannah River Company for the HWR and ANL, INEL, ETEC, LANL, LLNL, and ORNL for the MHTGR.

Review of anticipated technology needs for the HWR and MHTGR NPR concepts and the strengths and capabilities of the national laboratories led to the designation of ORNL by the Office of New Production Reactors as the Lead Laboratory (LL) for both concepts on Engineering Economic Analysis, Codes and Standards, and Staff Support and as the Center of Excellence (CoE) for MHTGR Fuel Development, Instrumentation and Control (both concepts), Materials Development (both concepts) and MHTGR Fission Product Transport. Additionally, ORNL was assigned technical support roles to other program participants for Nuclear Design, Reactor Vessel System and Vessel Head, Steam Generator, Main Circulator, and Severe Accidents, all for the MHTGR. A brief summary of ORNL's responsibilities for each of the LL and CoE assignments is shown below.

- *Engineering economic analysis*
  - — prepare cost-estimate guidelines
  - — maintain a cost estimating data base
  - — perform and coordinate independent cost reviews and evaluations
- *Codes and standards*
  - — review, coordinate, and issue NPR standards assuring consistency with DOE orders, national standards, NRC regulations, state and local standards, and software standards
- *Staff support*
  - — provide, as necessary, technical staff to augment the DOE technical staff at headquarters and in the field
- *MHTGR fuel development*
  - — identify fabrication, design, and safety issues associated with the various MHTGR fuel forms
  - — identify limiting accidents and resultant containment loadings
  - — perform experiments to quantify fuel performance under normal operating and transient conditions and to validate fuel performance models
- *Instrumentation and control*
  - — assess instrumentation and control options and requirements and identify technology developments needed to meet these requirements
  - — pursue subsequent development, design, qualification, and testing as needed
- *Materials development*
  - — provide the material-related information and data bases needed to properly select, fabricate, and utilize materials for NPR components
  - — emphasize effects of environment on behavior to assure safe and reliable performance over full service life
- *MHTGR fission product transport*
  - — demonstrate expected low levels of fission product release and transport
  - — provide validated design tools for analysis of fission product transport

Costs for base technology development and confirmation testing have been estimated at just over $300 million each for both the HWR and MHTGR NPR concepts in the period FY 1989 through FY 1994. This, of course, is an ambitious undertaking in terms of the scope of the technology programs, their schedules, and associated levels of funding. Completing these tasks for the NPR, during the period indicated above, will require a strong initiative at ORNL and at other laboratories (Table 16).

Table 16. Budget projections by fiscal year for New Production Reactor technology development ($ in millions)

1988	1989	1990	1991	1992	1993	1994
1.7	2.0	12.0	26.0	26.0	26.0	26.0

Advanced Control Test Operation

Modern automated reactor control systems can enhance the economic competitiveness of advanced reactors by increasing operational reliability, availability, and maintainability; improving safety by reducing challenges to the plant protection systems; and significantly reducing the skilled operator manpower needed to operate the plant. Automation is critical to the economic competitiveness of multimodular plants.

Within the Advanced Controls Program, a dedicated Advanced Control Test Operation (ACTO) laboratory is needed to support the design process for automated systems. ACTO will be capable of providing complete dynamic models of the entire nuclear plant, operating in real time, and being coupled to the proposed control system. The center will employ state-of-the-art computer technology, software engineering, integrated human-system development, component data bases, and artificial intelligence techniques to test and qualify advanced control systems. The laboratory will be comparable to the concept of engineering simulators and system prototype test centers being used for similar purposes in aerospace and military system development.

A space has been cleared and equipment has been set up in an existing ORNL building that will be used for the ACTO laboratory. As the program grows, adjacent laboratory space will be added as necessary. Ideally, the ACTO laboratory would be a separate facility dedicated to the Advanced Controls Program. A conceptual design was completed for such a laboratory to be located at ORNL. The capital cost to support this new laboratory will not be proposed for consideration within this planning period.

ACTO will become a research, development, and support center within the Advanced Controls Program. The center will support the development of modern control and automation technology, as well as the transfer of applicable technology from the space and defense sectors to the nuclear industry. The program will provide the necessary systems, tools, facilities, and simulation capabilities to support national laboratories, universities, small businesses, DOE contractors, reactor manufacturers, and utilities in developing and adopting new technology. This is an example of high-risk, long-term, high-payoff technology beyond the planning horizon of industrial decision making. However, we believe the potential benefits for the industry and the nation far outweigh its costs (Table 17).

Table 17. **Budget projections by fiscal year for Advanced Controls Program ($ in millions)**

1989	1990	1991	1992	1993	1994	1995
3.0	3.5	5.0	5.0	5.0	5.5	5.5

Bioprocessing in Energy Technology

Bioprocessing is expected to make important contributions to several aspects of the use of fossil and biomass energy and to enhance the use of fossil fuels, which will continue to be our most important source of energy for the next few decades. Because ORNL has established a leadership position in bioprocessing research, an expanded effort on bioprocessing for fossil and biomass energy is most appropriate. Although the forms of fossil fuels vary considerably (light oils, heavy oils, tar sands, natural gas, shales, numerous coals, etc.) and their current and conventional uses vary considerably (direct combustion, processing to more valuable liquid and gaseous fuels, conversion into chemical products, etc.), there are several aspects similar to potential bioprocessing. Similarly, opportunities exist for efficiently converting biomass feedstocks to liquid and gaseous fuels. A coordinated program at ORNL would provide useful interactions between related studies and would eliminate unnecessary duplication of effort.

Bioprocessing Applications

Enhanced Resource Recovery Microbial-enhanced oil recovery (MEOR) represents an innovative bioprocessing approach to the recovery of additional oil from exhausted reservoirs. It is thought that the microbial populations can either be used in surface facilities or injected underground to produce surfactants, polymers, solvents, and/or carbon dioxide that can interact with entrapped oil to enhance release. Similarly, microbial systems may be able to interact with the structures that tie up the hydrocarbons in oil shale and tar sands, thus enhancing the recovery of the included oil.

Only a limited amount of information is currently available on these concepts, although MEOR looks particularly attractive. To fully exploit these approaches, our understanding of the interactions between cells/enzymes and the interfaces between phases must be improved, and entirely new approaches to bioreactor configuration and predictive process models must be developed. For example, it might be appropriate to consider processing oil shale in heaps as is now done in the mineral industry, thereby obviating the need for enclosed reactors.

Coal Beneficiation Bioprocesses also can be used to enhance coal quality by the removal of heteroatom components such as sulfur and by modifying the coal surface to make it more reactive. Most of the research on biological beneficiation has been directed toward microbial removal of pyritic sulfur; however, the removal of metals, organic sulfur, oxygen, and nitrogen may also be possible. The optimum microbial population for these applications is not known, and the most efficient bioreactor configuration has not been established.

Conversion of Coal to Liquids and Gases It has been shown that some types of microorganisms and various enzyme systems can actually interact with coal to form a liquid product (Fig. 18). Concepts to convert coal to gaseous fuels

Fig. 18. Microbiological researchers Brenda Faisson and Susan Lewis examine cultures of coal-solubilizing fungi. These organisms are useful in the conversion of low-ranked coals to high-value products such as methane, fuel alcohols, and other liquid oxychemicals.

have also been developed, and demonstrations of the microbial conversion of fuel gases such as methane and syngas to liquid fuels have been conducted. These potential biological processes can be carried out at essentially ambient conditions, making them very attractive alternatives to the existing thermal/chemical processing approaches.

The use of biocatalysts in organic solvents is one intriguing approach that may revolutionize the bioprocessing of coal, although very little is known about the activity of biocatalysts in organics. Information is also needed on the bioprocessing chemistry, proper form of the biocatalyst, and probable concepts for these various possible bioprocesses.

Product Upgrading The liquid hydrocarbons that can be, or possibly could be, used for fuel may include undesirable heteroatoms and/or hazardous organic constituents. These materials are conventionally removed by severe hydrotreating at high temperatures and high pressures; however, we now know that several types of microorganisms will interact with such constituents, possibly removing them from the liquid fuel at mild operating conditions. An emulsion-type bioreactor will probably be required for applications of this type; however, very little is known about this, including the proper form of the biocatalyst.

Waste Treatment Advanced bioprocessing concepts have already been shown to be important in the cleanup of aqueous waste streams from processing facilities for fossil fuels, although predictive processing models of these systems are not yet available. It may even be possible to use certain bioadsorbents (microbial, plant, or animal biomass) to accumulate and remove dissolved heavy metals from such waste streams. Some evidence indicates that bioprocessing systems could also be used for treating product spills and solid residues, perhaps with in situ applications of the biocatalyst. Microbiological processing may prove useful in removing nitrogen and sulfur oxides from combustion off-gas systems, an approach that would require a bioreactor that could accommodate a biocatalyst in contact with a moist gaseous stream.

Biomass Feedstock Conversion Biomass represents a major renewable source of both chemical feedstocks and fuels such as alcohols. Biomass conversion to fuels will also be neutral with respect to the "greenhouse" gases as the production of biomass by plants consumes CO_2. Research has focused on the first part of biomass conversion—the breakdown or hydrolysis of the plant polymers (e.g., cellulose and lignin) into more easily usable forms such as glucose. Enzymatic hydrolysis has been shown to have major advantages in rate, yield, lack of harmful by-products, and mild operating conditions. The major disadvantage is the high cost of enzymes. An ongoing biotechnology project has greatly increased the ability to reuse the key enzymes of cellulase. Another effort is purifying the components of cellulase and elucidating their synergistic interaction. These efforts can expand into the optimization and scaleup of this process, can explore hydrolysis of other plant polymers, and can ultimately result in conversion into chemical feedstocks and fuels.

CO_2 Recycle Energy production from fossil fuels always results in large quantities of CO_2 in the off-gas waste streams that are released to the environment. Because of increasing concern over the continued release of large quantities of CO_2, it is appropriate to consider techniques for recovering this material, especially if recycling to a fuel material is possible. A potential approach is the photoreduction of CO_2 in conjunction with other substrates to hydrocarbons and oxychemicals by catalytic agents that are driven by solar energy. Biocatalysts, heterogeneous metal catalysts, or combinations of both types should be studied for this application.

Generic Bioprocessing Research

The similarity of bioprocessing opportunities for the various fossil energy sources is evident, and advances in one area are likely to be helpful in other areas. Also, some areas of bioprocessing research in fossil energy will be common to solar energy applications, conservation programs, and environmental control technology for hazardous and radioactive materials. Thus, a coordinated effort for supporting generic bioprocessing research should also be considered. This could include the development of improved bioreactor concepts; the identification and development of more efficient biocatalytic agents (microorganisms, enzymes, and plant and animal tissues) used with the most effective immobilization techniques; study of efficient bioseparation systems; and the generation of techniques for system integration and modeling.

Proposed Program

An enhanced and coordinated R&D program is proposed for ORNL that would properly address the potential benefits of bioprocessing in fossil energy. The work will be organized and carried out in the Bioprocessing Research Center (BRC); the center will include a bioprocessing research users facility that will be available for use by other laboratories, universities, and industry. A broad range of original bioprocessing research and development will be carried out by the BRC staff, encompassing many of the areas listed above. A primary emphasis will be on advanced bioreactor concepts and bioseparations. One of the highlights of the program will be the interaction with and support of university research. A number of universities have excellent faculty and adequate resources to carry out important research in this area. Several highly qualified university faculty members within chemical or biochemical engineering departments have already expressed a specific interest in participating in such cooperative research.

The industrial sector will be included in the research partnership by the availability of the users facility for proprietary and nonproprietary industrial research and by inclusion in the activities of the center. An aggressive program will be maintained to transfer developed technology to the industrial sector. In this respect, the ORNL Office of Technology Applications will be supporting the development of industrial contacts, including the licensing of patented technology. Workshops will be organized and held with the specific aim of keeping the industrial sector aware of important research and development results.

ORNL is currently receiving some funding for bioprocessing from DOE-Fossil Energy, the Solar Energy Research Institute, and private industry. Funding in the future could also come from the Biomass Program of DOE-Conservation and Renewable Energy. Table 18 shows the proposed budget.

Table 18. Budget projections[a] by fiscal year for Bioprocessing in Energy Technology ($ in millions)

	1989	1990	1991	1992	1993	1994	1995
Operating	0.5	2.0	5.0	8.0	9.0	12.0	15.0
Capital	0	0.4	0.5	0.8	0.9	1.2	1.5

[a]This budget allows for an expanding program during the first 3 years, followed by a constant budget adjusted for inflation for 1 year and moderate increases for the 5th and 6th years. The latter increases are expected to be needed to establish technical feasibility of concepts previously developed.

Scientific and Technical Programs

Department of Energy

Office of Energy Research

The Oak Ridge National Laboratory's major research programs in the basic physical sciences, fusion energy, and biomedical and environmental sciences areas are supported by the Office of Energy Research, the largest single sponsor of research at ORNL (Table 19).

AT—Magnetic Fusion

The Fusion Program at ORNL is a major component of the Office of Fusion Energy's Magnetic Fusion Program. Two characteristics make it unique 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 ORNL divisions, and major

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

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
AT	Magnetic Fusion[b]	45.4	41.6	40.3	42.8
AT	GPP and GPE	11.0	9.7	13.7	16.0
KA	High-Energy Physics	0.5	0.8	1.5	1.4
KB	Nuclear Physics	14.6	14.8	16.2	16.7
KC	Basic Energy Sciences	71.0	77.8	85.1	124.8
KD	Energy Research and Analysis	1.1	1.5	1.1	0.9
KE	University Research Support	0.4	0.8	1.0	1.0
KG	Multiprogram Energy Laboratories Facilities Support	27.4	27.7	25.1	28.3
KP	Biological and Environmental Research	24.5	26.3	27.2	28.8
Total		195.9	201.0	211.2	260.7
Percentage of total Laboratory funding—BA		43.9	43.1	38.1	41.6

[a]Includes funded operating BA, capital equipment, and funded/proposed construction as noted in construction tables and Table A.5 in the Appendix.
[b]Includes Compact Ignition Tokamak (CIT) funding from Princeton Plasma Physics Laboratory.

contributions are made by the Engineering, Computing and Telecommunications, and the Oak Ridge Y-12 Plant organizations.

The goal of the National 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 (D-T)]. 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 sufficiently good to allow energy confinement times of several seconds at plasma densities of $10^{14}/cm^3$. 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, and lithium blankets to breed tritium. These components must withstand, or be protected from, the fierce 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 alternative energy sources. Today's research in magnetic fusion addresses several key issues:

- understanding toroidal confinement, with particular emphasis on tokamaks operating in the first stable region, in support of Compact Ignition Tokamak (CIT) and International Thermonuclear Experimental Reactor (ITER) design phases;
- developing magnetic configurations that provide good insulation at high beta and that have attractive engineering features;
- understanding the physics of plasmas burning deuterium and tritium;
- developing technologies for producing, heating, fueling, and controlling such plasmas; and
- developing fusion nuclear technologies and materials for the fusion reactor environment.

Support for the ORNL program comes from three subprograms: Applied Plasma Physics (AT05), which funds theory, atomic physics, and diagnostic development; Confinement (AT10), which funds confinement experiments, the CIT, and some applied plasma technology; and Development and Technology (D&T) (AT15), which funds technology, ITER, and systems studies.

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 systems simplify analysis, while the differences can be exploited to isolate specific physical phenomena. The most notable difference is instability 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 Advanced Reactor Innovation and Evaluation Study (ARIES)]. Low-aspect-ratio tokamak ideas developed at ORNL have led to plans for experimental tests of such devices at several sites, and for collaboration, most notably at the Culham Laboratory of the United Kingdom Atomic Energy Authority. Major collaboration will continue with the world stellarator program to develop key future experiments in Japan, Europe, and the Soviet Union. Studies of an advanced toroidal facility (ATF-II) to test the physics of an attractive toroidal reactor continue. The development of data bases and theoretical models for atomic physics and fusion plasma diagnostics has been undertaken in the Physics Division. A powerful new source of multiply charged ions has, within the past several years, contributed 90% of the available ionization cross-sectional data base for fusion-relevant ions and should give many years of fruitful research. In a separate program, a very promising laser-based diagnostic for fusion alpha particles is being installed on ATF for proof-of-principle tests.

The main focus of the Confinement subprogram at ORNL is the ATF experiment, which started operating in 1988 (Fig. 19). The two primary helical coils produce a magnetic field of 2 T and have been constructed and assembled within the required accuracy of ±1 mm in 5 m. The ATF has outstanding capabilities: It (1) has the flexibility to study various magnetic configurations and to provide a very important beginning to the understanding of toroidal confinement; (2) has already accessed the second stable region of operation, which promises improved performance for tokamaks and stellarators (Fig. 20); and (3) will 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. Base plasmas have been created using electron-cyclotron heating (ECH) with densities up to 10^{19} m^{-3} and central electron temperatures up to 800 eV. These clean plasmas

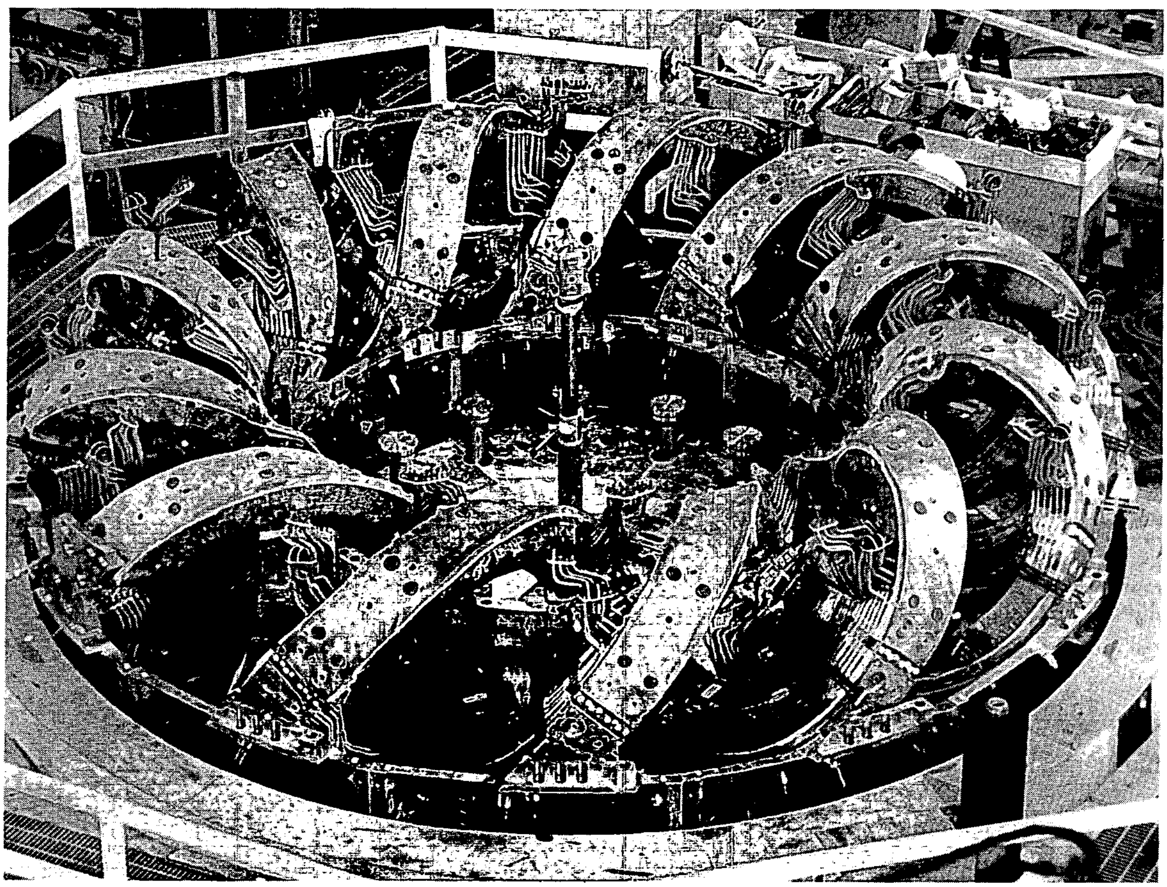


Fig. 19. The advanced toroidal facility, which was completed in December 1987, produced its first fusion plasma in January 1988.

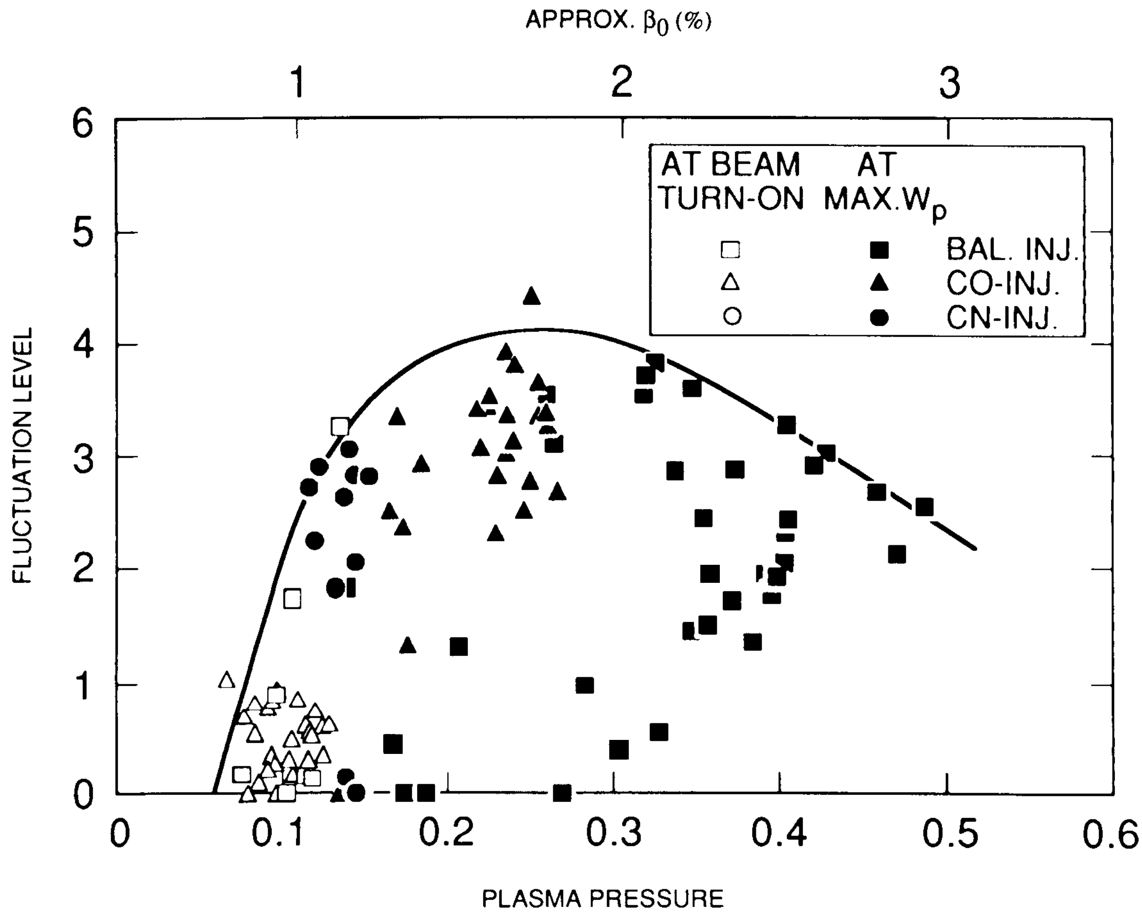


Fig. 20. As plasma pressure rises in the ATF, plasma instabilities increase at first. Then turbulence decreases and the plasma enters the region of "second stability."

are used as targets for neutral-beam and ion-cyclotron heating. Central betas up to 3.0% have been achieved with 1 MW of neutral-injection heating. A problem with magnetic-field errors arising from nonsymmetries in the coil current leads has been corrected. This correction and the use of improved diagnostics, pellet fueling, and higher powers should improve studies of transport and beta in 1990.

The Confinement 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) (Federal Republic of Germany) and Tore Supra (France). In addition, a similar major program using the ATF will be undertaken on limiters, divertors, edge-plasma diagnostics, and surface physics. New activities involving collaboration on divertors, heating, and diagnostics have started with the Doublet III group (General Atomics) and TEXT group (University of Texas at Austin).

The D&T subprogram at ORNL continues to make impressive contributions throughout the breadth of its work. With the completion of a summary report for the Large Coil Program*

*"The IEA Large Coil Task; Development of Superconducting Toroidal Field Magnets for Fusion Power," ed. D. S. Beard, et al., *Fusion Energy and Design* 7(1&2): 1–232, 1988.

(LCP), the Magnetics and Superconductivity Section personnel have turned to superconducting development for nonfusion applications.

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. Such systems are commonly referred to as rf systems. The ORNL Radio Frequency Test Facility (RFTF) is a major element in the development and test of the rf launching structures. Ion cyclotron frequency heating systems have been built for the Doublet III-D tokamak at General Atomics, Tokamak Fusion Test Reactor (TFTR) at Princeton Plasma Physics Laboratory, ATF at ORNL, and Tore Supra in France (Fig. 21). ORNL scientists will participate in rf heating experiments on these machines. ORNL is responsible for the CIT rf heating system and is building an antenna system for Alcator C-Mod at the Massachusetts Institute of Technology; this antenna system will be prototypical of the CIT system. In addition to these major heating systems, state-of-the-art rf components developed at ORNL are being used at many experiments worldwide.

The principal long-term method of fueling plasmas is by the injection of high-speed (>2000 m/s) pellets of solid hydrogen. The

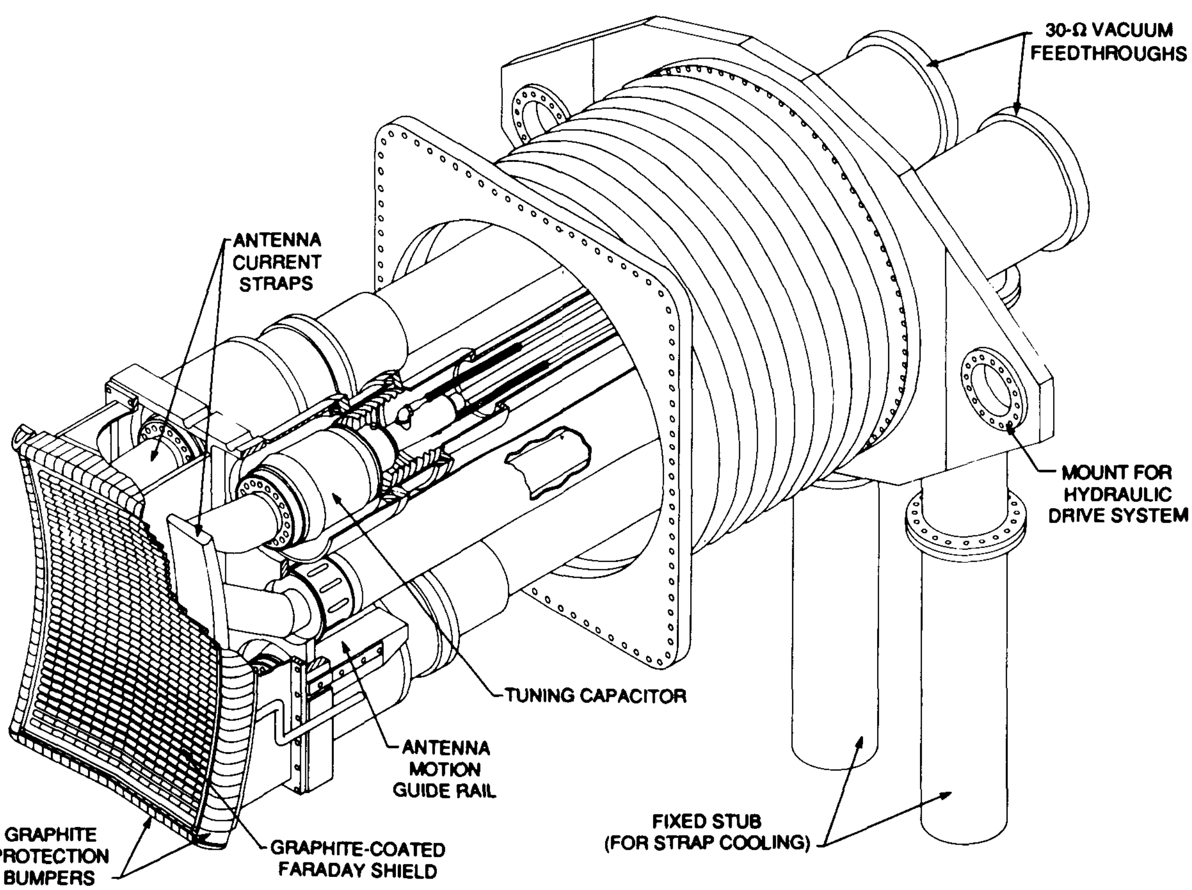


Fig. 21. Layout of the 4-MW long-pulse antenna for Tore Supra. Each current strap was designed for a 50-kV peak at 800 rms and was tested on the RF Test Facility at ORNL. The antenna has graphite-covered Faraday shield elements and a protection bumper to minimize plasma impurities.

pellet-injector program continues to be one of ORNL's outstanding contributions to the advancement of world fusion. ORNL hydrogen pellet injectors have been used for fueling many U.S. experiments and are planned for use in many more. A system has also been supplied to the Joint European Torus (JET), a project of the European Economic Community. An injector is also being built for Tore Supra. In mid-1988, the system installed on JET was used to produce centrally peaked high-density plasmas for ion cyclotron range-of-frequency (ICRF) heating experiments. A factor of from 2 to 3 improvement in confinement time was seen. A factor of 4 improvement in the fusion reaction rate was also reported. A tritium pellet injector has been built and tested. Concepts are being studied for alternative fueling schemes, while advanced concepts are being tested for producing significantly higher-velocity pellets.

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 theory and development of steels to withstand the fusion neutron environment. A new thrust of the program is to concentrate on alloys that will have low induced radioactivity. Promising austenitic steel compositions with favorable mechanical properties have been produced. Some of these alloys will be tested in the upgraded High Flux Isotope Reactor (HFIR) irradiation facilities. Other programs involving ceramics and copper have been initiated, and a multiyear collaboration with the Japan Atomic Energy Research Institute (JAERI) is under way.

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 collaborates extensively with U.S. industries, national laboratories, and universities and also plays a major role in the physics, engineering, and systems studies for ITER. A project organization has been formed with the Fusion Energy Division, which has substantial responsibility for the heating, fueling, shielding, magnet-insulation vacuum systems, and remote-handling systems for the CIT project. During the past year, the FEDC also contributed to the ARIES tokamak reactor study headed by the University of California at Los Angeles.

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

- To play a major role in the new U.S. program initiative to improve the understanding of toroidal confinement. Key elements of the contributions will be 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, materials, and superconductivity.
- To give special emphasis to the new remote-handling programs now under way for TFTR and CIT.
- 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 plasma-heating and current-drive systems.
- To maintain a strong position for Oak Ridge to be the site for major D-T burning plasma facilities in the future.

KA—High-Energy Physics

The High-Energy Physics Program is anticipated to grow significantly during the reporting period as a result of activity related to the national Superconducting Supercollider (SSC) project. The program almost doubled in size from FY 1988 to FY 1989 and is expected to exceed that growth again in FY 1990. In addition to existing activity in radiation-shielding design and a joint UT/ORNL experimental high-energy physics program, the new activity includes high-energy particle-nucleus collision modeling and development of novel high-performance preamplifiers for use in calorimeter detectors. Assistance is also provided to the SSC project by temporary assignment of a superconducting magnet specialist to work at DOE headquarters. Each of the current high-energy physics research and development activities is expected to grow and increase in focus and cohesion as the proposed High-Energy Physics Research and Detector Development Center is established (see Initiatives). This joint ORNL/SURA/ORAU initiative will provide the vehicle for a significant contribution from ORNL and participating universities of the Southeast to the SSC project and to the science of high-energy physics.

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 (AIM) funds ($545,000) are expected in FY 1990 for upgrades 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. Also in September a new technique was demonstrated for the sputter generation of group 1A atomic negative ions.

Several new or significantly improved detector systems are expected to be in heavy use at the HHIRF during the reporting period. One of the new devices that is expected to be heavily used 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 (BRS) for high-multiplicity particle-gamma coincidence measurements. The newly completed close-packed array of Compton-suppressed germanium detectors will make possible higher resolution and more detailed studies of nuclear properties at high spin and temperature (Fig. 22). The multiphase Heavy-Ion-Light-Ion (HILI) logarithmic counter for detecting coincident reaction products over a wide range of particle masses, energies, and reaction angles will be completed. First experiments with the early phases of this device have demonstrated an excellent dynamic range for studies at the energies accessible by the HHIRF accelerators. Another major new addition will be the Recoil Mass Separator (RMS), a $2.2-million device jointly sponsored by ORNL, ORAU, Idaho National Engineering Laboratory (INEL), and a number of universities. This apparatus will be designed and assembled early in the planning period with initial operations planned for FY 1991.

ORNL staff members are involved in the proposal for a national 49-gamma-ray detection facility, the Gammasphere (see Initiatives), 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. Because of existing facilities at the HHIRF, the cost for site preparation and installation would decrease to about $750,000.

Computing facilities will be upgraded with the implementation of several Advanced Computer Project multi-microprocessor systems. Initially

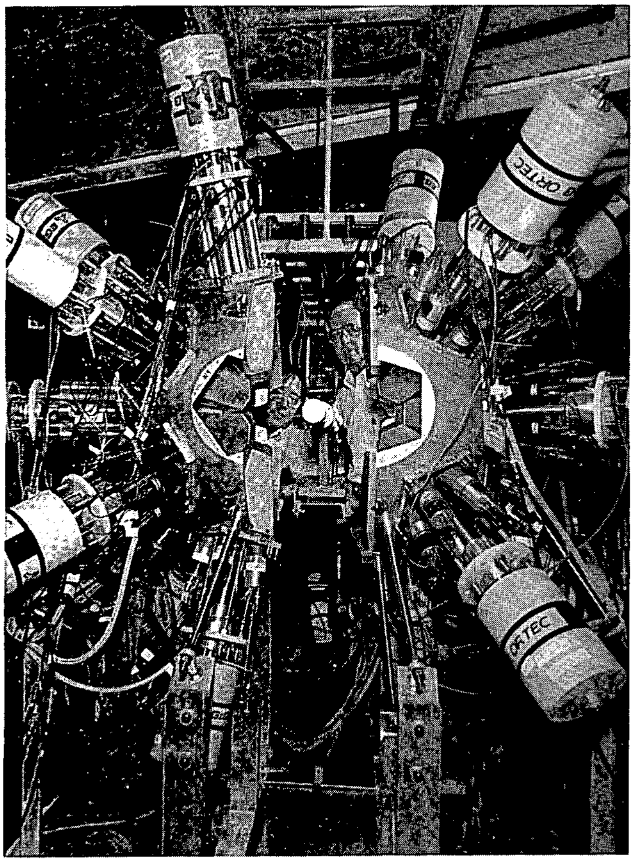


Fig. 22. ORNL researchers Noah Johnson (right) and I. Y. Lee, architects of the Compton-Suppression-Spectrometer system, watch as the close-packed array is fitted around the reaction chambers.

utilized for processing the volumes of magnetic data tapes generated in experiment WA80 at the Conseil Européen pour Recherche Nucléaire (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 (BNL) and at CERN.

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

- mean field [time-dependent Hartree-Fock (TDHF)] 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;
- the physics of the (e+, e−) system at very short distances; and
- pion propagation in nuclear matter.

With the recent addition of an ORNL-UT 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 of Nuclear, Atomic, and Particle Computational Science (CNAPCS) has been proposed that would request joint funding from the state of Tennessee and DOE.

KB04—Low-Energy Physics Program The Low-Energy Physics Program supports several tasks, including operation of ORELA, a unique pulsed neutron source accelerator facility for measurements by time-of-flight spectrometry of neutron cross sections and related quantities over the entire range from 0.002 eV to about 80 MeV. Funding is also provided for related activities in the acquisition and evaluation of neutron cross-section data, computer code development, neutron scattering, and gamma-ray spectroscopy. This program also supports a large effort in studying the simple modes of nuclear excitation evidenced through giant resonances. These studies make extensive use of the HHIRF and GANIL (France) facilities.

Other funded activities include the Nuclear Data Project, an evaluation center responsible for collecting and evaluating nuclear structure information for 70 mass chains in the mass region

$A > 199$. New initiatives include a complete upgrade of the ORELA rf drive system and replacement of the existing data acquisition computer system. In connection with the DOE program of environmental restoration, the nuclear data base for actinides will be reevaluated, and additional measurements will be planned as appropriate. The usefulness of neutron transmission cross-section measurements as quantitative indicators of the presence of specific waste materials in intensely radioactive samples will be investigated.

KC—Basic Energy Sciences

The Basic Energy Sciences (BES) Program supports a broad spectrum of research in the physical sciences. The two largest subprograms are the Materials Sciences (KC02) and the Chemical Sciences (KC03). Several key issues face these subprograms, including restart of the Bulk Shielding Reactor (BSR), development of the Advanced Neutron Source (ANS) (see Initiatives), 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; 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 (SMAC/CRC), 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, High-Temperature Superconductor R&D, Microwave Sintering of Ceramics, and the Advanced Research Center for Materials Science and Engineering. 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.

Increased emphasis is expected for research on the structure of materials. One growth area 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 also 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 applied to new materials and properties made possible by ion-beam technology and to 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.

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.

A new initiative in this area is a proposed theoretical and experimental study of the effects of microwave radiation on materials and on kinetic processes in materials.

The chemistry of advanced inorganic materials is a significant research area in which synthetic control of composition, purity, and morphology is emphasized. 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 which will lead to the reproducible production of pure and mixed ceramic precursors. Since 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.

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, and molecular dynamics simulations. Used in combination, these are revealing often unexpected structural 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 will receive a boost from restart of the HFIR reactor. 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. The neutron-scattering program focuses on the structure and dynamics of condensed-matter systems. The active neutron-scattering users programs at the HFIR will expand with the restart of the reactor.

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 (Fig. 23) [glow discharge, rf, electron cyclotron resonance (ECR)], and microanalytical and electrical characterization. Active research areas include

- fundamental studies of ion implantation in semiconductors (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;
- development of laser photochemical vapor deposition for athermal growth of heterostructures and compound semiconductors;
- laser ablation deposition of high-temperature superconductors (Fig. 24);
- fabrication of optical waveguides using ion implantation;
- development of ECR plasma processing for damage-free deposition and etching of submicron structures; 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,

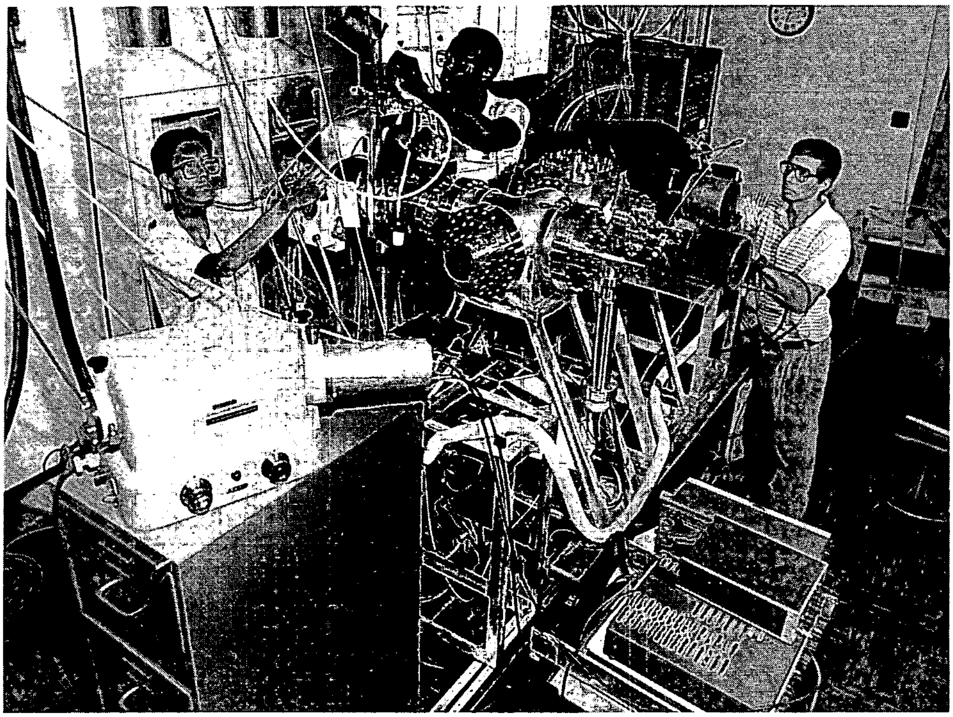


Fig. 23. Research staff member Steve Gorbatkin (right) and summer student research participants Joseph Lee (left) and Deon Williams (center) adjust the Solid State Division's Microwave Plasma Processing System.

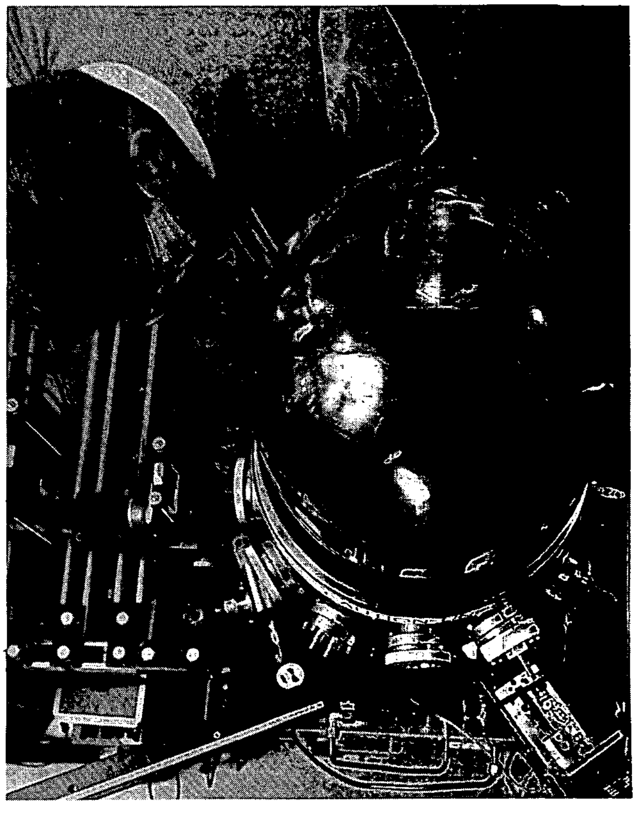


Fig. 24. High-quality thin films are produced at ORNL by deposition of superconducting materials using a laser-ablation technique. The BES Program is supporting spectroscopic studies of the plumes produced by laser ablation to further understand the process.

superconductors, optical materials, ceramics, and novel electronic materials such as diamond. The research is carried out in collaboration with more than 50 scientists from industry and universities, many of whom perform research at ORNL facilities, such as the accelerators and lasers at the SMAC/CRC.

The Isotopes Research Materials Laboratory (IRML) is a unique national resource for R&D on materials processing methods used to provide the international research community with stable and radioactive isotopes in useful forms. It is the most diverse isotope-processing facility in the world, and its extensive facilities and expertise in vacuum, metallurgical, ceramic, and thin-film technology will continue to be used to discover and develop new methods for processing large and small amounts of actinides; radioisotopes; enriched stable isotopes; and normal assay metals, gases, and ceramics.

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

KC03—Chemical Sciences The Chemical Sciences Program supports the HFIR, the Radiochemical Engineering Development Center (REDC), isotopes separation, and the atomic physics and basic chemistry programs. 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. Some 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 electron-cyclotron-resonance (ECR) ion source. The emphasis of these studies is on characterizing the energy and angular distribution of ejected electrons. The ECR source and EN Tandem Accelerator 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. A major initiative of this group is the proposed HISTRAP Facility (see Initiatives).

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 QED 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 of Nuclear, Atomic, and Particle Computational Science described in the KB03 discussion.

Preparations for restart of the HFIR reactor were intense over the more than 2 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. Because the HFIR is unique in that it offers a combination of high flux with a mixed spectrum, low-irradiation temperatures, and flux tailoring, the facility is valuable for material-damage studies related to the

Magnetic Fusion Program and design of other advanced reactor concepts such as the ANS.

The Transuranium Processing Plant (TPP) and Thorium-Uranium Recycle Facility (TURF) have been renamed the Radiochemical Engineering Development Center (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 5f electrons that are heavily influenced by relativistic effects for 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, organometallic chemistry, magnetic behavior, and plans for the first photoelectron spectroscopic study of 5f ionization dynamics of a free actinide atom. Ability to perform state-of-the-art relativistic quantum mechanics calculations has also been added to the program.

The Isotopes Program is essential for production of both stable and radioactive isotopes used in medical applications and in basic research. This program has three components at ORNL: electromagnetic isotope separations, HFIR irradiations, and transuranium-element processing at the REDC. A number of funding scenarios have been discussed for the Isotopes Program, including the possibility of removing it from the Basic Energy Sciences program altogether. At this time, the future of the Isotopes Program remains uncertain.

Part of the analytical chemistry program moved in FY 1989 to the recently built Organic Chemistry Mass Spectrometry Laboratory. An Inorganic Chemistry Mass Spectrometry Laboratory will be completed in FY 1990. Approximately $1 million in BES funds will be spent for new equipment for these two laboratories from FY 1989 to FY 1991. 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 continues to improve existing analytical techniques and to develop new ones. Some of the methodologies under investigation include

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

A unique array of complementary experimental and modeling techniques is applied to study thermodynamics of interactions and reactions in highly nonideal aqueous solutions 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. Use of several UHV and surface reaction approaches is being expanded by incorporation of synchrotron-based approaches from a previous program whose emphasis was on photodynamics of molecular species rather than surface-adsorbed species.

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 NMR techniques to chemically modified coals and the use of surface-immobilized compounds for thermolysis studies.

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 study the fundamental physico-chemical aspects of the conversion of light energy into chemical energy using artificial photosynthetic systems. This research is in part directed at synthesizing a simplified photosystem capable of producing fuel from renewable resources. Another growth area is in the use of electromagnetic fields to enhance the efficiency of separation processes. The focus of this research is on improving mass transfer in liquid-liquid solvent extraction, analysis of electric-field effects in liquid droplet formation, and microscopic droplet transport phenomena. 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.

Research on separations reagents is focused on better understanding of the chemical and structural principles that determine selectivity in solvent extraction systems for metal ions. Particular emphasis has been placed on the use of synergistic combinations of macrocycles, such as the crown ethers, and organophilic acids as tailored ligands. Structural and equilibrium extraction studies, molecular mechanics simulations, and organic synthesis are combined to design and prepare improved ligands. More emphasis is being placed on combining the required coordination and charge neutralization functions into single, polyfunctional extractants.

Research in separation phenomena is comprised of several fundamental studies that address the issue of the use of electromagnetic fields to enhance the efficiency of multiphase separations processes. In these studies, emphasis is placed on understanding the underlying hydrodynamical interactions that lead to augmented performance. Currently, the effort is focused upon improving mass transfer in liquid-liquid processes through the use of high-intensity electric fields. 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 which 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. A new 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. It will draw heavily on concepts and methodology developed in an earlier program on molten salt chemistry.

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 human-scale manipulative capabilities (Fig. 25). Funding is expected to increase slightly during the reporting period. New emphases will be three-dimensional world modeling using laser-imaging scanner data and control and allocation of heterogeneous resources (i.e., man-robot symbiosis and 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) 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 research and development of robotic intelligent machines for operation in hazardous, unstructured environments. Existing relationships with the decontamination and decommissioning effort at the Oak Ridge Gaseous Diffusion Plant (ORGDP) offer the possibility of measuring technological progress in real-world environments. The proposed mechanism for developing the robotics aspect of the ORNL waste R&D plan is an increase of

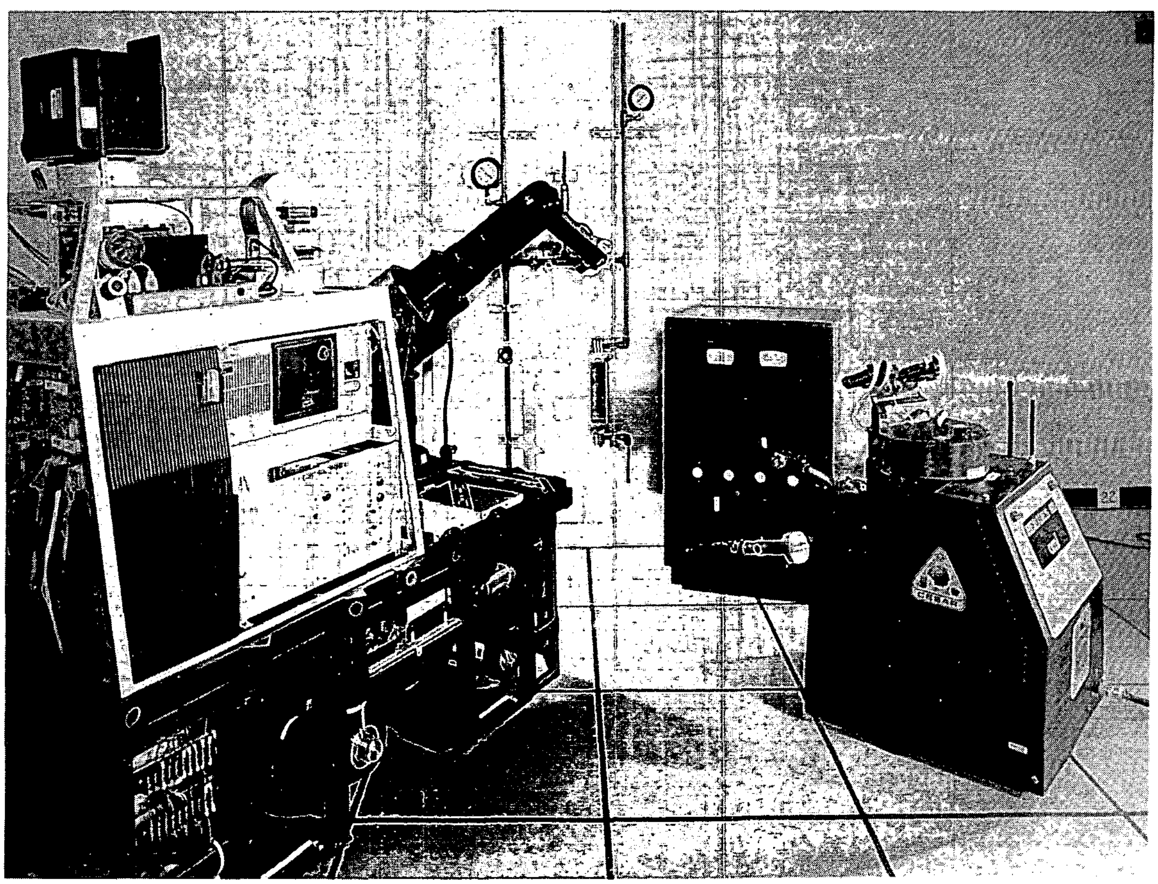


Fig. 25. Cooperating mobile robots, HERMIES-III and HERMIES-IIB.

approximately $1 million in operating dollars and $0.5 million in equipment dollars per year for the CESAR program.

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 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 The Advanced Energy Projects Program supports exploratory research at moderate levels, typically for 3-year durations. In FY 1989, a project to study methods of recovering cellulase enzymes from aqueous solutions and undigested solid residues will be completed. A second project is funded from FY 1989 to 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. It is expected that additional exploratory research programs will be supported during the planning period in areas such as cold fusion and the recycle of carbon dioxide.

KC07—Applied Mathematical Sciences The Applied Mathematical Sciences Program supports research in parallel-processing algorithms and the development of applied mathematical and statistical methods for analyses of physical processes. These research activities are supported by the Oak Ridge Advanced Computing Laboratory (ORACL), which provides research computers with a variety of architectures that are in various stages of development. Parallel architectures currently in ORACL include an Intel iPSC/2, an NCUBE/4, a Sequent Balance 8000, and a Cogent multiprocessor workstation. A multi-gigaflop parallel computer will be acquired in FY 1990.

The following will continue to be major research areas: sparse matrix computations, performance characterization, 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 to meet the computationally intensive needs of today's computer models. New proposals in KC07 include support for research in genetic algorithms and support for research in uncertainty representation and kinematics. A new initiative for ORNL involving the KC07 program was presented in the Initiatives section, entitled "Grand Challenges in Computational Science." A second new initiative, the Center for Mathematical Environmental Modeling, is described below. This initiative also supports two other initiatives discussed in the Initiatives section: (1) Multifaceted Research, Development, and Demonstration Program in Hazardous Waste Management and (2) Global Environmental Sciences. The expertise developed in the Applied Mathematical Sciences Program will be one of the key foundations for developing these new initiatives.

New Initiative—Center for Mathematical Environmental Modeling The United States has spent (and undoubtedly will spend) billions of dollars on problems associated with hazardous wastes (chemicals, radioactive materials, etc.). Proper treatment of such wastes poses exceedingly difficult technical problems involving multiple interactions of complicated physical processes in heterogeneous and anisotropic geologic structures. Development of effective technologies for remediation and monitoring of waste sites requires a better understanding of these complex processes. For many years it has been recognized that mathematical modeling and computer simulation of subsurface flows could provide important information and insight to complement laboratory and field research; however, only recently has adequate computer power, in the form of multi-gigaflop parallel machines and high-speed three-dimensional graphic display devices, become available to develop and use realistic, detailed, three-dimensional simulations.

Development of a Center for Mathematical Environmental Modeling has been undertaken as a joint venture involving mathematicians and scientists at ORNL and at several universities. The mission of this center is to promote and strengthen mathematical research applicable to environmental problems in four ways:

- develop and analyze mathematical techniques for modeling waste-management problems and develop and implement efficient algorithms embodying mathematical models of such problems in computer simulations on parallel computers;
- provide access to parallel-computing resources for researchers developing mathematical and computational methods applicable to environmental problems;
- facilitate and encourage collaboration and discussion among mathematical researchers interested in such problems and assist in a transfer of knowledge to practitioners in the applications areas; and
- develop and maintain strong ties with the various communities of scientists (environmental, geophysical, geological, and hydrological) to obtain experimental data for constructing physically realistic models and to test the usefulness of model predictions and to disseminate tools and results to users.

Some proposed areas of research include

- *Flow in fractured rock.* Subsurface fractures can have a significant effect on contaminant flow. Improved mathematical techniques are needed to allow modeling of realistic fracture geometries. This will provide a better understanding of the interaction between the fractures and the surrounding porous media.
- *Control and optimization problems.* Formulation and analysis of difficult control and constrained optimization problems are required to determine cost-effective site-remediation strategies.
- *Mathematical methods for site characterization.* A fundamental problem in attempting to accurately model contaminant transport is the limited ability to characterize the physical properties (required by computer models) of the site. The development of mathematical techniques in the area of stochastic differential equations can assist in defining the types of field measurements that need to be performed.
- *Contaminant transport.* Contaminant transport coupled with an auxiliary process development of effective site-remediation techniques will be aided by an understanding of biologically and chemically active, multiphase flows. The development of mathematical algorithms for modeling such flows would allow expensive field testing to be supplemented with simulation runs, thereby increasing our understanding of these processes.
- *Inverse flow problems.* From field data, one would like to be able to identify the most probable source of a contaminant plume. The solution of such inverse problems has thus far received very little attention.

In analyzing three-dimensional problems, the ability to create realistic model geometries and to visualize the results of a calculation is crucial. An important aspect of this work is therefore the integration of state-of-the-art computer-graphics technology.

As a multidisciplinary national laboratory, ORNL has many of the resources required for this project: applied mathematicians experienced in the numerical solution of partial differential equations on parallel machines; computer scientists and the essential parallel-computing hardware; statisticians knowledgeable about geostatistics; and equally important, strong local interest in environmental engineering, with active programs in various aspects of waste management. The university principal investigators provide, in addition to their extensive technical expertise, leadership and experience in mathematical analysis, algorithm development, and environmental modeling.

Preliminary discussions have been held among ORNL researchers Richard Ewing (University of Wyoming), James Glimm (State University of New York at Stony Brook), and Mary Wheeler (University of Houston) to define the center's mission and objectives. A preproposal has been submitted to the Applied Mathematical Sciences Program of the DOE Office of Energy Research. The initial response has been very positive.

Budget projections for this initiative are provided in Table 20. Partial funding for a multi-gigaflop parallel computer expected in FY 1991, and a more powerful and massively parallel computer expected in FY 1992, is included under operating funds because they will be purchased under a lease-to-ownership arrangement.

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 the reporting period. FY 1989 work included technical support for peer review assessments of Toxicology (OHER), Photovoltaics (Conservation and Renewable Energy), and Control Technology and Coal Preparation (Fossil Energy).

KE—University Laboratory Cooperative Program (ULCP)

In FY 1988, through the ORNL-obligated portion of ULCP, financial support was provided to over 100 student and faculty research participants under a variety of programs, including the science semester programs, nuclear-engineering training experiments, and health physics internships. ULCP 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 ULCP at ORNL are providing opportunities for participants from MEIs and expanding precollege programs. In FY 1988, ULCP supported the summer appointment of over 20 faculty and students from MEIs. The ULCP 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. The program was expanded in FY 1988 to include modules in the physical sciences. In FY 1988, over 9000 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, called 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 University and Educational Programs provides financial and

Table 20. Budget projections by fiscal year for the Center for Mathematical Environmental Modeling ($ in millions)

	1988	1989	1990	1991	1992	1993	1994	1995
Operating	0.0	0.1	0.5	1.5	2.0	2.0	2.0	2.0
Capital	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1

technical resources for CRESO, seeing its mission as an extension to the EPSSC.

ORNL is the lead laboratory in an effort involving five other DOE laboratories toward the development of a proposal for a national precollege program to be sponsored by the National Science Foundation.

The other focus continues to be MEIs, with an increasing role expected for Hispanic institutions as the result of two agreements signed in FY 1988: a memorandum of understanding (MOU) signed with the University of Puerto Rico (UPR) and the MOU signed in November 1987 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.

KG02—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. 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 (GPPs) 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 (Fig. 26). A treatment plant for removal of heavy metals and organic contaminants from process wastewater was completed during FY 1989. 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 low-level radioactive and/or hazardous chemical wastes. This funding category conducts 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, including their transport, chemical evolution, adverse health effects, and ultimate consequences in humans and their 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.

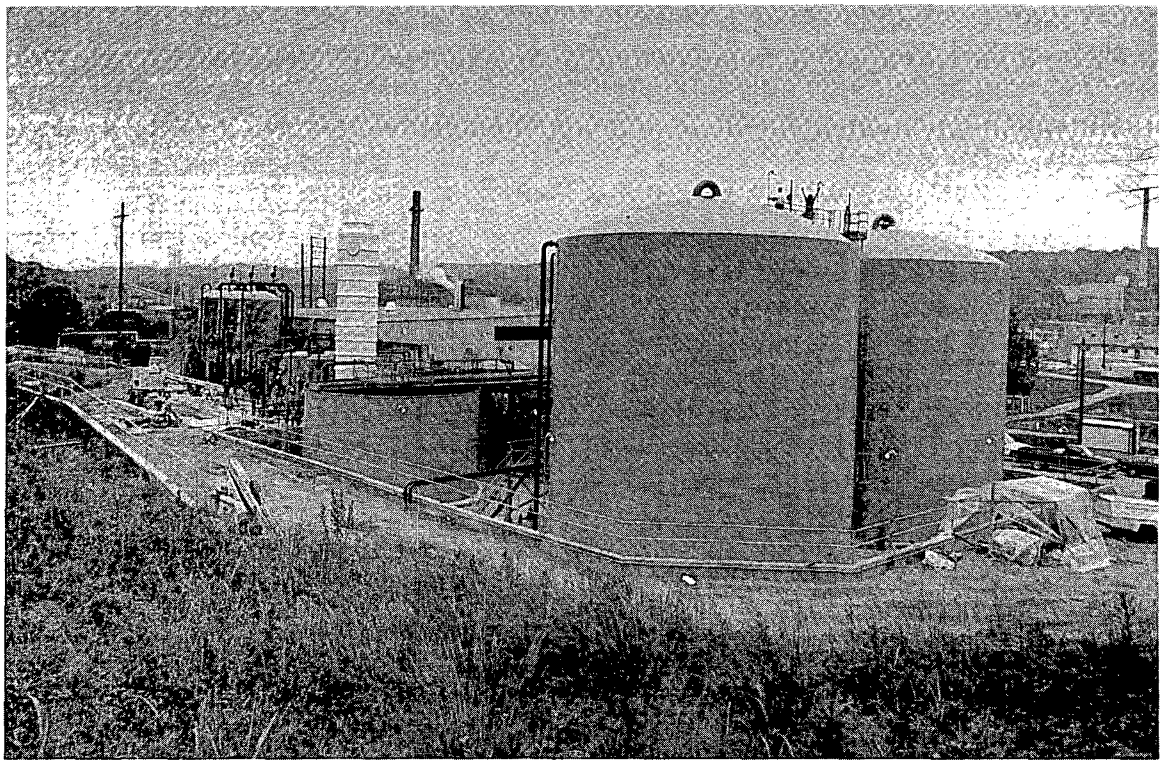


Fig. 26. Construction of the Nonradiological Wastewater Treatment Plant was completed during FY 1989. The plant will treat ORNL's nonradiological process wastewaters in accordance with permit requirements established by EPA and the Tennessee Department of Health and Environment. The treatment plant and associated tankage and collection systems constitute an $18 million project which provides enhanced National Pollution Discharge Elimination System environmental compliance capability.

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 toxicology, global environmental studies, ecosystem studies, geosciences, hydrology, environmental assessment, 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, three unique user facilities are supported by the KP Program: the Health Physics Research Reactor (HPRR), the Oak Ridge National Environmental Research Park, and the Bioprocessing Research Facility (BRF) User Resource. 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 most multidisciplinary life sciences research programs in the nation and covers a broad range of both basic and applied studies. Overall, the KP program at ORNL is expected to experience growth in global sciences, subsurface transport studies, human genome research, and radon-related research in this planning cycle.

Biological Sciences Common themes among the research programs of the Biology Division are interactions of animals, cells, and molecules with their respective environments. Investigations focus on genetic and somatic effects of radiation and chemicals. Goals include identification and quantification of these effects, elucidation of pathways by which the effects are expressed, assessment of risks associated with radiation and chemical exposures, and establishment of strategies for extrapolation of risk data from animals to humans. Concurrent basic studies in genetics, biochemistry, molecular biology, and cell biology illuminate normal life processes as prerequisites to comprehending mutagenic and carcinogenic effects of environmental agents. The Biology Division will continue to emphasize three programmatic areas: mammalian genetics, protein engineering, and radiation carcinogenesis.

In mammalian genetics research, increasing emphasis will be placed on molecular techniques for genome studies. Two major approaches will be taken to identify and characterize the DNA structure of genes or genomic regions that have significant developmental functions.

1. Microinjection of foreign DNA into fertilized ova will be used to produce transgenic mice that carry new mutations caused by the integration of foreign DNA in the vicinity of host genes. These gene loci are therefore tagged with the foreign DNA and can be readily cloned and characterized. In addition, new DNA integrations throughout the genome could potentially be used to analyze the molecular biology of already existing mutations, including those previously induced by radiations or chemicals.
2. For genomic regions in which large radiation-induced deletions are available, finely structured functional maps will be generated by new techniques of in vivo saturation mutagenesis. These functional maps will be correlated with the DNA structural maps that are being generated by a variety of molecular techniques for the same regions.

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.

Increased emphasis will also be placed on mouse models for human developmental anomalies and specific genetic disorders. Risk assessment of exposure to significant environmental chemicals will continue. Human cytogenetics will continue to play a major role in identifying mutagenic pathways. The use of restriction enzymes to disrupt chromosomes at specific sites is providing new insights into mechanisms by which chemicals and irradiation induce chromosomal aberrations and mutations (Fig. 27).

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 is 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 (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

Fig. 27. Chinese hamster metaphase cell showing many chromosome alterations induced by the restriction endonuclease Rsa I. The arrow heads indicate some of the large number of interstitial deletions.

(EGF), a polypeptide hormone that stimulates cellular growth and differentiation; and O^6-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. We have focused on residues previously assigned to the active site and therefore anticipated that the designed structural changes would be detrimental, as has indeed been the case. Catalytic deficiency of a carboxylase mutant can be due to any one of several possibilities: (a) improper folding of the polypeptide, (b) failure of subunits to associate to form a dimer, (c) inability to undergo carbamylation as required for activation, (d) failure to bind substrates, or (e) loss of a group that participates directly in catalysis. In the cases of position-166, position-329, and position-48 mutant proteins, we have established that in all probability the deficiency is due to loss of a catalytic group (lysyl ϵ-amino groups at positions 166 and 329 and a glutamyl γ-carboxylate at position 48). Our next goal is to pinpoint, in the overall reaction pathway, the precise step at which each of these three residues participate. We will also use mutagenesis and chemical modification in concert to introduce extremely modest structural changes, heretofore not feasible, into the active site to explore the potential for altering the enzyme's specificity for gaseous substrates.

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 epidermal growth factor (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*. Current studies have identified several amino acids that are required for proper recognition of the cellular receptor. Preliminary data have also indicated targets for amino acid substitutions that produce antagonists of EGF that may inhibit growth of tumor cells. Some of these mutants will be tested directly as inhibitors of cell proliferation and also tested for their mitogenic activity. Besides monitoring stimulation of DNA synthesis, some of the early effects of EGF on animal cells, namely, increase in Ca^{2+} and glucose uptake, accumulation of inositol phosphates, change in pH, etc., will be investigated.

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 *E. coli* protein is more complex than the mammalian methyltransferase in that it also acts as a regulatory protein for transcriptional control of its own as well as that of other alkylation repair genes. The 39-kDa Ada protein has two alkyl acceptor cysteine residues. Cys-321 accepts alkyl groups from O^6-alkylguanine and O^4-alkylthymine. Cys-69 accepts alkyl groups from alkyl phosphotriesters, as a result of which, the alkylated Ada becomes a transcriptional activator of the genes of the *ada* regulon by binding to a conserved sequence, which is 5′-upstream of the promoters of the repair genes. 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.

We are exploring the possibility of introducing a number of silent mutations in the *ada* gene such that unique restriction sites will be created. This modified gene will be used as a target for cassette mutagenesis, particularly in the Cys-321 region and in the putative helix-turn-helix region in the N-terminal domain. One obvious site for mutation in the C-terminal domain is Pro-320, an invariant amino acid also present in thymidylate synthetase (next to the active site Cys), where it has recently been shown to be essential for activity. His-322 will also be replaced by alanine to see whether it plays a role in methyl group transfer.

Additional gene products under close scrutiny include enzymes involved in transcription of DNA and membrane-transport proteins responsive to environmental insults.

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 (LET) 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.

Molecular genetic techniques are being used to define the mechanisms of hormonal regulation of gene expression and the action of regulatory genes involved in differentiation. The role of transposable genes in the development of malignancy and genes that control the neoplastic expression of the oncogenes will continue to receive considerable attention.

Radiation is used to determine the role of specific molecular and chromosomal alterations in the induction of leukemia. In vivo–in vitro epithelial cell systems will be applied to the determination of the role and mechanisms of cell-to-cell interactions in radiation carcinogenesis. 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.

Leukemias are the quintessential radiation-induced cancers in humans. In the case of myeloid leukemia, a specific chromosome aberration is associated with the disease. In mice a putative specific chromosome aberration is associated with myeloid leukemia. Both the specific chromosome aberration and the specific leukemias occur at a relatively low incidence in unirradiated mice and at higher and dose-dependent levels in irradiated mice. It is possible that more than one chromosome aberration is involved. The natural incidence and the susceptibility are significantly greater in males than females. 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 (Fig. 28), 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.

Fig. 28. Karyotype of a cell from a line established from the spleen cells of a leukemic mouse. The deletion of one chromosome, No. 2, indicated by a bracket on the normal chromosome, is a very consistent chromosomal alteration in leukemic mice.

Considerable publicity has been given to the likelihood of greatly increased incidences of skin cancer as a consequence of elevated ultraviolet-B (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.

An indicator of the change in gene regulation during carcinogenesis is the change in various proteins, including those on the cell surface. A protein complex that is a member of the integrin family has been identified on both human and murine cancer cells. Monoclonal antibodies to different subunits of the complex have opened up possibilities of tumor imaging and therapy. A monoclonal antibody to an epitope on the endothelium in the lung has been developed that also has potential for specific tumor imaging and drug delivery.

New Initiative—Structural Biology An interdivisional (Biology, Analytical Chemistry, Health and Safety Research) effort is intended to develop support for structural biology through OHER (Table 21). A core proposal that includes biological applications of scanning tunneling microscopy, Fourier transform mass spectrometry, X-ray and neutron scattering, and X-ray crystallography is presently under review by OHER. To date, modest activities have been funded by Laboratory seed money programs, other overhead accounts, or other agencies.

The scanning tunneling microscope (STM) operates at ambient temperature and pressure and scans under water or salt solution. The instrument provides images that can be photographed from an oscilloscope screen. These images can also be processed by computer graphics, yielding false-color images of atoms on the surface of a crystal in one color and the second layer of atoms in another. The instrument has achieved subatomic resolution of conducting materials. For biological specimens, the problem is one of sample preparation. In theory, nonconducting biomolecules should not be resolvable, and several laboratories have obtained their best images with metal-coated specimens. The resolution in these cases is far from atomic and only in a few instances is significantly better than conventional transmission electron microscopy (TEM). Nevertheless, clear images of unstained, uncoated tobacco mosaic virus and DNA (Fig. 29)

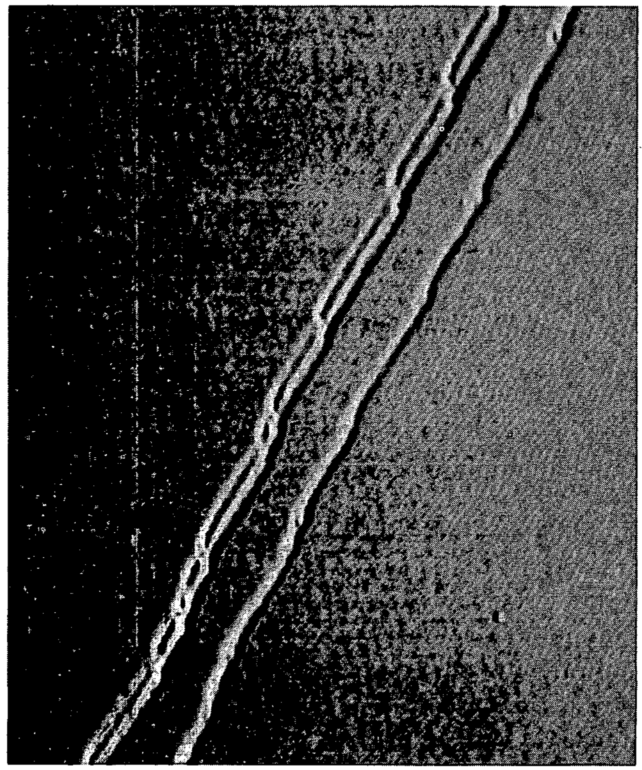


Fig. 29. This STM image of the DNA from the pBR322 plasmid was obtained on graphite after endonuclease treatment to relax the supercoiled structure (scan area 200 × 200 nm). Because the helical turns show a 6-nm repeat, it does not conform to the standard right-handed DNA double helix that has a repeat of ~3 nm. New and unexpected structures such as the nodes shown in this image also remain to be explained. Plans to perform mapping and sequencing of DNA and the human genome by STM are being formulated.

Table 21. Budget projections by fiscal year for the Structural Biology Initiative ($ in millions)

	1989	1990	1991	1992	1993[a]	1994	1995
Operating	1.9	2.3	2.3	2.4	2.5	2.6	2.6

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

have been obtained at ORNL. Current work is focused on obtaining negative replica images from samples coated with small, conducting materials (e.g., carbon). The use of STM for biological samples is still under development, and the samples being examined include small viruses of known structure to establish the baseline for examining materials of unknown structure.

A major use of Fourier transform mass spectrometry (FTMS) is to identify and quantify carcinogenic and mutagenic lesions in DNA (e.g., alkylation sites). FTMS offers the extreme sensitivity necessary to detect the one modified base per chromosome that may account for a detrimental effect. Because small restriction fragments would normally be analyzed, sequence information in addition to the identity of the modified base would be provided simultaneously.

X-ray crystallography of nucleosomes, the core particle of chromatin, has been funded as an appendage to the NSF-supported National Center For Small-Angle Scattering Research (NCSASR). Because of the HFIR shutdown, NSF withdrew its funds and restoration is unlikely. Without new core support from OHER at $400,000 annually, the Laboratory's lead position in nucleosome structure will be lost (ORNL is the only American institution in which nucleosomes have been crystallized). A major focus will be refinement of the crystal structure at 3-Å resolution of a nucleosome associated with a single human gene. Other projects would entail three-dimensional structure determination of human epidermal growth factor and mutant analogs designed by the Protein Engineering Program as well as a DNA repair protein that removes alkylation lesions.

In anticipation of the Advanced Neutron Source (ANS) to be constructed at ORNL as a dedicated user facility, OHER should consider funding two on-line scattering instruments ($3–4 million) and equipment for a biological sample-preparation laboratory ($1 million) to ensure world-class facilities to users from the biology community. Support of an adjunct biophysics group during the instrument design phase of ANS is also essential.

Environmental Sciences Environmental research is designed to increase our understanding of the transport and effects of energy-related contaminants in the environment. Basic information is developed on mechanisms that govern ecosystem function, particularly in biogeochemical cycling studies on forested landscapes and streams (Walker Branch Watershed). ORNL, in consultation with OHER, has reoriented and integrated existing terrestrial and aquatic projects on Walker Branch Watershed to focus on the hypothesis that positive and negative feedbacks between biotic and abiotic processes control the structure and productivity of forested watershed ecosystems. This focus is the basis for research on the ecological response to chemical emissions, emphasizing both aquatic and terrestrial environments. By using process studies with stable elements, radionuclides, and trace organics (as well as mathematical simulation models), data and methodologies are developed that enhance the capability to site and operate energy systems in a cost-effective and environmentally safe manner.

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. New emphasis will be placed on testing and 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 (i.e., the National Park Service).

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 (see Initiatives), which is housed in the Environmental Sciences Division (ESD) and involves staff from several other ORNL divisions as well as outside collaborations. Research on vegetation response to air pollution stress (particularly O_3, SO_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 effect 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, but includes atmospheric-deposition inputs, subsurface hydrologic transport, and element cycles and effects in streams. ORNL is an important research center for OHER in global carbon-cycle modeling and in the study of CO_2 effects on vegetation (Fig. 30).

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 (Fig. 31). 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.

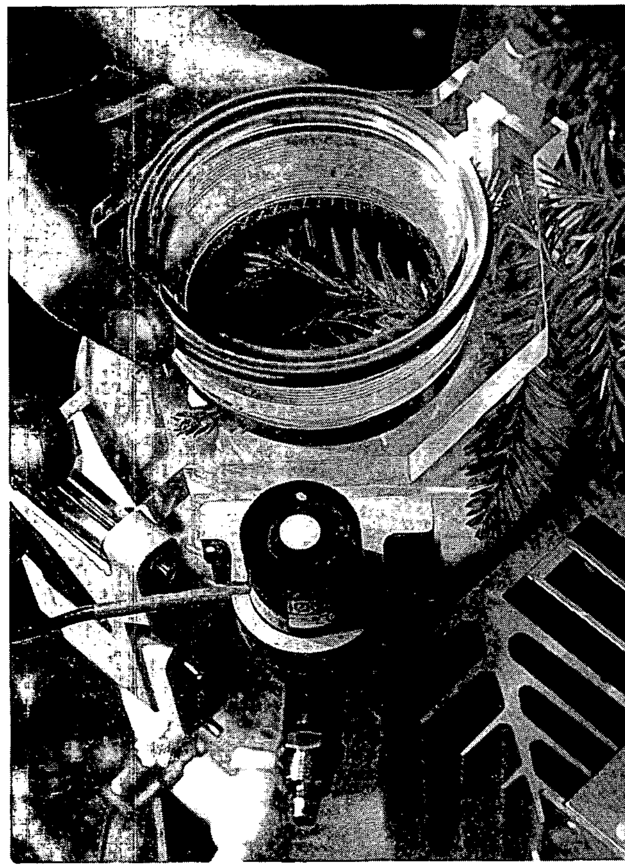


Fig. 30. ESD researchers use sophisticated photosynthesis measuring devices to study the impacts of atmospheric pollutants on plants.

The Oak Ridge National Environmental Research Park project is being redirected to include networking with the other five DOE Parks through the PARKNET system (Fig. 32). The project will focus on

- integration and synthesis of existing data across parks;
- coordination of activities among parks;
- on-site data management and data organization, including establishment of computer data bases of historic data; 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

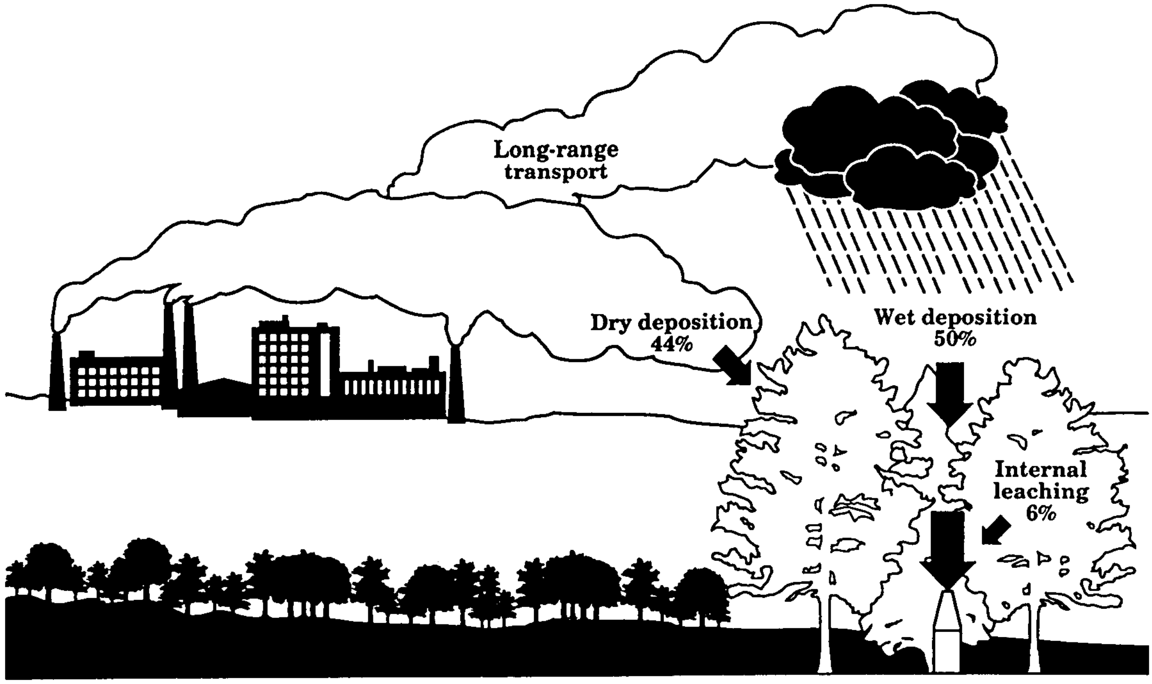


Fig. 31. Deposition of sulfur compounds as sulfate, and not acidity per se, is the key link between the atmosphere and ecosystem acidification. Scientists in ESD, with funding from DOE and EPRI, have used ^{35}S to test newly developed throughfall methods to determine the flux of airborne sulfur to forests. Their results indicate that the overwhelming majority of the sulfate in throughfall below trees in forests in industrialized areas is derived from atmospheric deposition and not from internal cycling. (The average fraction of the total sulfur deposition is given as a percentage.)

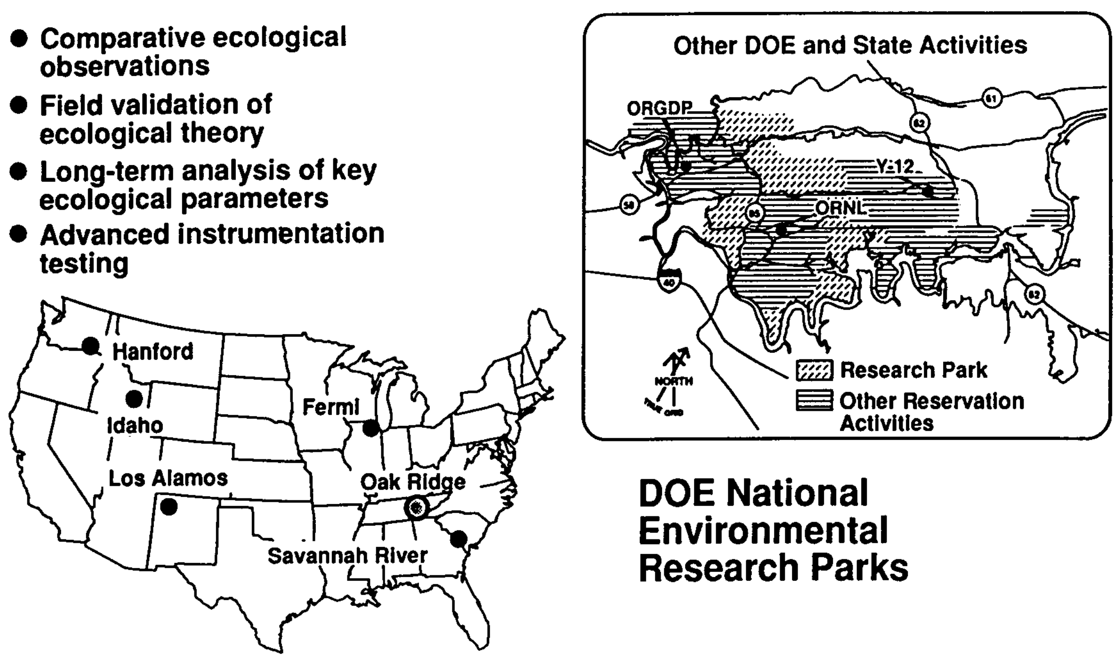


Fig. 32. The Oak Ridge National Environmental Research Park is one of six parks in the United States making up DOE's network of environmental research parks (PARKNET).

chartered as a component of the Man in the Biosphere Southern Appalachian Biosphere Reserve.

A program area in Resource Analysis, being managed by ORNL's Carbon Dioxide Information Analysis and Research Program (CDIARP), is supporting the studies that DOE-CDRP is conducting to analyze the measures that society might take in response to the effects of increasing atmospheric CO_2 and changing climate on natural and societal resources. The major tasks managed by CDIARP include making recommendations for the optimal definition(s) of regions to be used in regional-scale studies of the effects of changing CO_2-climate and collecting and providing quality assurance of data bases used in these studies. Additional tasks in Resource Analysis include the evaluation of the potential effects of CO_2 climate change on environmental resources and the study of climate model output.

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 (Fig. 33). 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.

The objective of the Carbon Dioxide Information Analysis Center 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

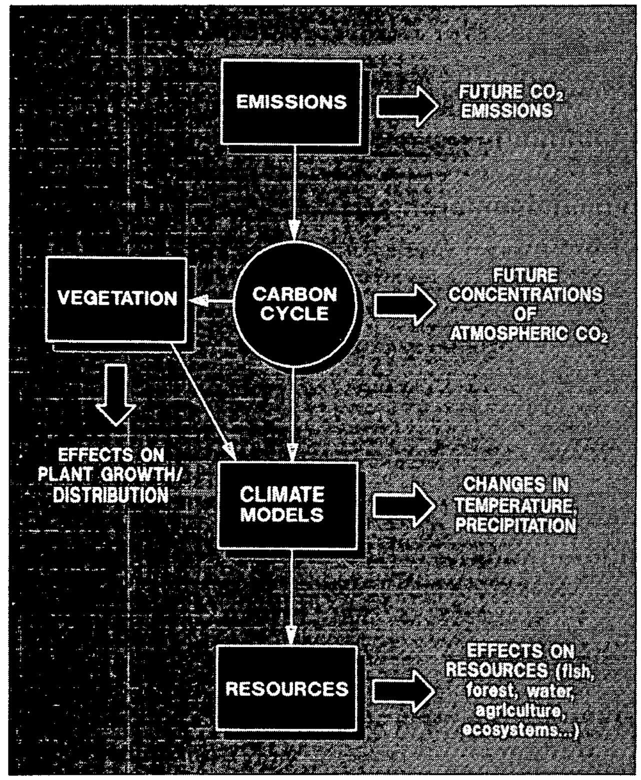


Fig. 33. Unraveling the CO_2-climate change issue.

compiling, analyzing, and handling data and other information. The center's activities will include research in all aspects of the CO_2 issue and technical management aspects of the national CO_2 program.

New Initiative—Subsurface Research We will continue our work in the areas of hydrology, geochemistry, and colloid chemistry in support of DOE programs in site-directed subsurface transport of hazardous substances and subsurface microbiology (Fig. 34). 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 as it will represent an essential element in the waste R&D plans (Table 22). Presently, activities at ORNL consist

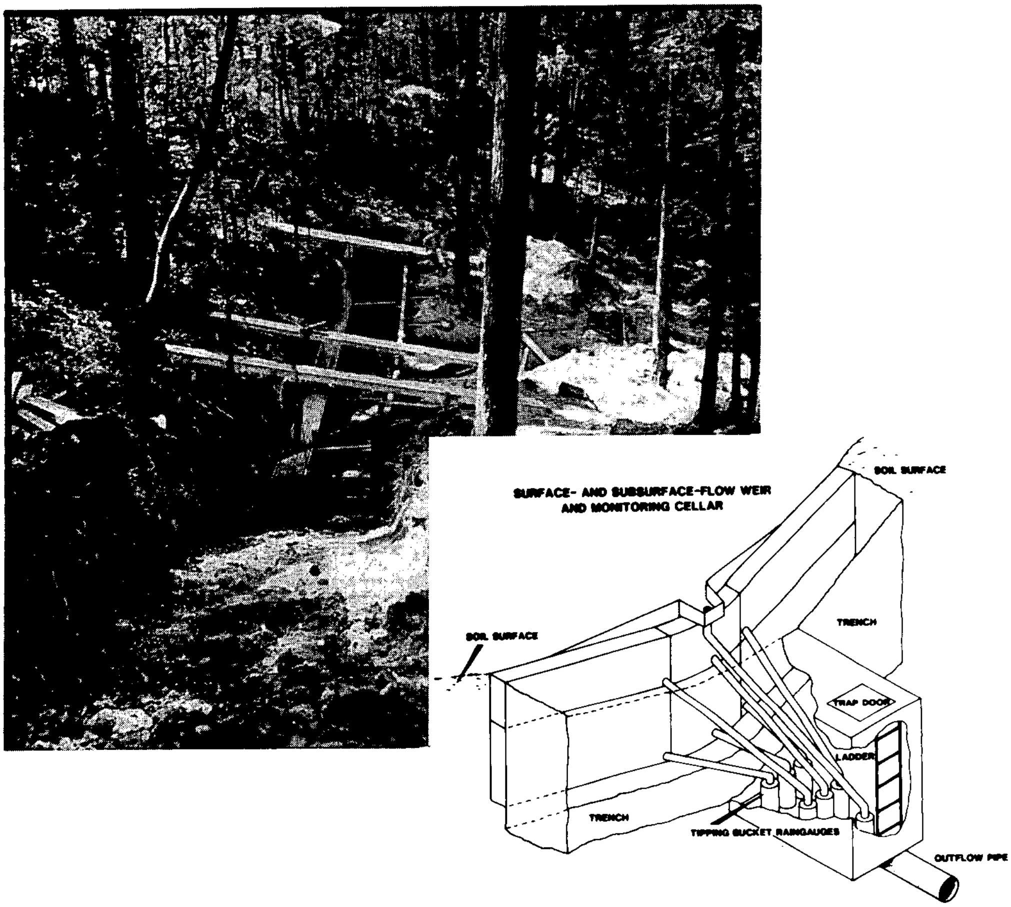


Fig. 34. A forested subwatershed (0.45 ha) has been equipped for an intense study of the roles of physical and chemical characteristics of soil on subsurface contaminant transport during precipitation. The photograph (upper left) shows the subsurface weir in Bethel Valley during construction. The drawing (lower right) is the completed facility as it exists below grade. The facility is used to study the behavior of organic and inorganic contaminants as they flow through the unsaturated zone and interact with soils and other materials. The application of the results from these studies is made to waste sites and allows predictions on contaminant mobility away from sites.

Table 22. Budget projections by fiscal year for the Subsurface Research Initiative ($ in millions)

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

of laboratory and field studies that are integrated with the development and application of hydrologic and chemical transport models. 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 contaminant migration in the subsurface in a humid environment.

Health and Safety Research A broad-based research program in the Health and Safety Research Division (HASRD) is directed toward increasing our knowledge of detrimental effects of all types of energy production. Included in this program are development 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.

OHER support of the physical and technological research activities is directed toward delineating interactions of potentially hazardous agents with biological and environmental systems. A second goal is ensuring that an adequate technical capability exists to characterize and quantitatively measure such agents under various circumstances.

In this program, 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.

In the technological research areas, 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 and subpicosecond processes in liquids, gases, and molecular clusters concentrates mainly on studies of their structure and dynamics relevant to energy deposition. The experimental data have direct bearing on problems of early-time chemistry in radiological insult to solid and liquid biological materials and on numerous highly reactive chemical species of atmospheric interest.

Monte Carlo calculations are also performed to simulate the fast physical and chemical processes that occur in materials following irradiation. These calculations are then compared with experimental measurements to identify the fundamental mechanisms of damage to biological molecules, which results from different types of radiation, including that from radon and its progeny. We are also studying basic physical and chemical properties of radon and its progeny as they relate to particulate formation and transport in the atmosphere.

Research at the HPRR is funded through the Biological and Environmental Research (KP) Program. The main objective of the HPRR is to conduct and support basic research in radiation and personnel dosimetry, radiobiology, radiation effects on materials and components, and dosimetry training. As a designated ORNL user facility, this program has historically been a strong supporter of technology transfer. Because KP-related research funds have become insufficient to adequately support the HPRR, a broad base of scientific interest in using the facility was developed in the national and international community.

Additionally, the HPRR has become easily available to these scientists since it was designated as an ORNL user facility. The Dosimetry Applications Research Group expects to continue to use this facility for nuclear accident dosimetry and personnel dosimetry intercomparison studies. This OHER-sponsored research represents only a small fraction of the HPRR usage. The programmatic responsibility for the operation of HPRR may be assumed by the major users of this facility.

The HPRR was shut down in March 1987 and is expected to restart early in FY 1990. Administrative oversight of the HPRR may shift from OHER to another DOE program with greater programmatic use. OHER use of the facility has remained constant over recent years while other programs have had increasing demands on HPRR time. This is a long-term trend, and while it may be appropriate for OHER to give up its oversight responsibilities, OHER should remain committed to continuous, long-term low-level use of this facility.

Construction of the Radiation Calibration Laboratory (RADCAL) was completed in FY 1988. RADCAL is in the process of being outfitted with a variety of beta, gamma, neutron, and X-ray radiation sources configured to deliver precise doses at specified locations. The purpose of this facility is to (1) perform personnel and radiation dosimetry research, (2) perform dosimeter intercomparison studies, and (3) test personnel radiation dosimeters for compliance with various national and international standards. Training and industrial support in radiation calibration and dosimetry will contribute to a strong technology transfer program at RADCAL. Operating and capital expenses associated with RADCAL are shown in Table 23.

The Health and Safety Research Division has received funding since FY 1987 to study the subsurface source, transport, and entry of radon-bearing soil gas into residences. 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 1987–1989, the program was supported jointly by DOE-OHER, EPA, and TVA. The DOE funding level will likely remain at $150,000 in FY 1990. Other radon research projects within the Health and Safety Research Division include investigation of progeny ion atmospheric interactions, interaction with biological materials, and radon dosimetry.

Because of increased awareness of and concern about radon as a cancer-inducing air pollutant, the Biology Division also received funding in FY 1988 for two different studies. One of these is evaluating the induction of neoplastic transformation of tracheal epithelial cells by alpha particles, and the other is applying new cloning techniques to permit quantifying of radiation-induced mutations. The funding level for FY 1990 will exceed the initial allocation of $150,000.

A continuing core research program exists in the Health and Safety Research Division to develop instrumentation and methodologies to detect chemical contaminants in the environment. The focus of the effort is to develop more cost-effective monitoring techniques to apply in the laboratory and in the field to reduce the expensive and time-consuming commitment to a regime of

Table 23. Budget projections by fiscal year for the Radiation Calibration Library ($ in thousands)

	1989	1990	1991	1992	1993	1994	1995
Operating	370	387	404	422	441	461	461
Capital	25	25	30	30	35	35	35

environmental samples undergoing analytical chemical analysis. A combination of basic research into the physical properties of detection of various organic chemicals and practical field application of those prototype instruments and methods provides a strong systematic process to move technology from the laboratory to the private sector.

The primary emphasis of the ORNL Nuclear Medicine Program is the design, synthesis, and preclinical testing of new radiopharmaceuticals for imaging and therapy (Fig. 35). Increased efforts are being placed on antibody and nucleoside labeling. A new component of the program will provide for more efficient transfer of new technology from research to production scale. Once a new technique shows promise, further clinical evaluation is conducted through our extramural Medical Cooperative Programs with collaborators in the United States and Europe. Once demonstrated, a vigorous technology transfer effort is undertaken to effect transfer to the commercial sector via a licensing agreement. These new technology transfer efforts complement our traditionally strong emphasis on journal publication of our research results. Prominent contributors to the continuing success of the Nuclear Medicine Program are the restart of the HFIR and the future availability of the Advanced Neutron Source (ANS).

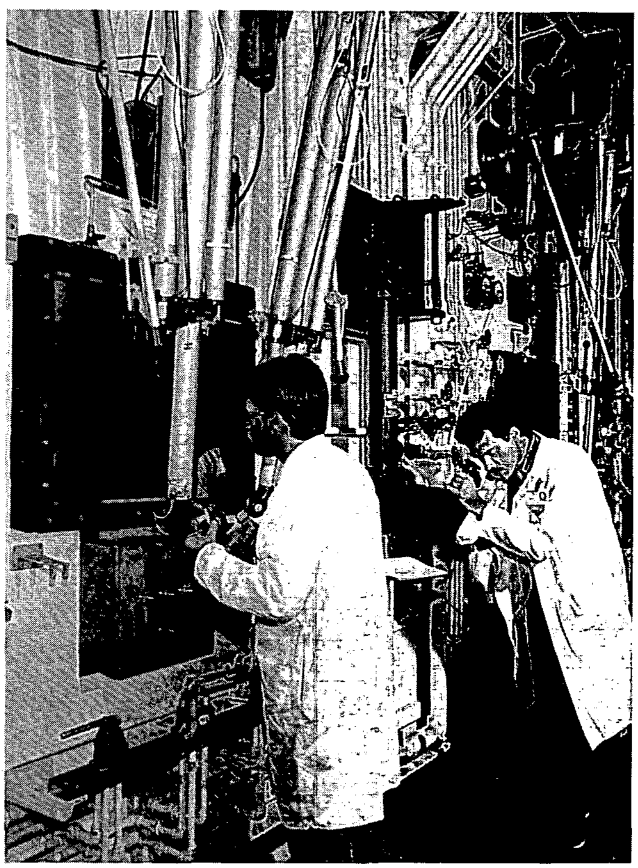


Fig. 35. Technical support staff process radioactive material used in the development of new radiopharmaceuticals for diagnostic and therapeutic applications.

We continue to have a major commitment to the radiation protection community to develop and maintain state-of-the-art methods for estimation of the dose to radiosensitive tissues of the body from both external and internal radiation exposures. In addition to addressing specific issues of immediate importance to DOE, we play a significant role in supporting the International Commission on Radiological Protection, the National Council on Radiation Protection and Measurements, and the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine. Efforts to improve current methods focus on developing physiologically based models for behavior of radionuclides in the body and improving estimates of dose to cells and tissues at risk. We are in the process of moving from mathematically based phantoms to discrete element phantoms obtained from computerized tomography scans for use in our dosimetry codes.

A major goal is to develop new methods and instruments to improve the ability to measure biomedical and ecological parameters of importance, especially biomarkers of exposure to, or potential dose from, toxic agents. Close interaction among biochemists, spectroscopists, and ecologists has led to numerous successes, permitting measurement in situ and in real time. An important new area of emphasis involves development of new DNA-sequencing technology with funding from the Director's R&D Fund.

A multidisciplinary research effort on biological indicators that integrates resources from several divisions is continuing. Research efforts are directed toward developing, understanding, detecting, and applying biological indicators of exposure and/or human health and ecological effects associated with energy technologies and hazardous waste sites. Examples of human health and biomarkers include direct or indirect measures of internal dose or measures of biochemical/biophysical alterations of biological targets of the ecosystem. These research efforts will continue to identify improved and sensitive tools to monitor critical biological indicators and will also contribute to a better understanding of the effects of energy-related mutagens and carcinogens on human health and ecosystem viability.

New Initiative—Human Health Risk Analysis ORNL has been involved in health risk analysis for many years through programs established in the Health and Safety Research Division. However, most of this effort has been supported by Work-for-Others funding. Recent emphasis on hazardous wastes associated with DOE facilities, as well as other hazardous waste sources, and the corresponding resources required to remediate past waste problems provide strong incentives for performing high-quality health risk assessments to ensure that the desired and appropriate risk reductions are achieved at minimum costs. Our Human Health Risk Analysis Initiative will focus on necessary research required to develop improved health risk analyses for cost-effective remediation of hazardous waste sites. The initiative will focus 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. Total support for this initiative is projected to grow to a $6 to $10 million annual budget within the next 3 years (Table 24).

Assistant Secretary for Nuclear Energy

The Assistant Secretary for Nuclear Energy (NE) is the major sponsor of applied nuclear research at ORNL. Programs funded through this office are multidisciplinary and include nuclear energy R&D, remedial actions, and uranium enrichment (Table 25).

AF—Nuclear Energy R&D

Consolidated Fuel Reprocessing Program The Consolidated Fuel Reprocessing Program (CFRP) 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 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. To date, Japan has fully committed $3.4 million for this; approximately $10 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

Table 24. Budget projections by fiscal year for Human Health Risk Analysis Initiative ($ in millions)

	1989	1990	1991	1992	1993	1994	1995
Total funding	2.0	3.0	4.5	6.0	8.0	10.0	10.0

Table 25. Assistant Secretary for Nuclear Energy major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year 1988	1989	1990	1991
AF	Nuclear Energy R&D	28.9	32.4	43.1	47.2
AH	Remedial Actions and Waste Technology Programs	7.4	5.0	3.2	4.3
AJ	Naval Reactors	0	*b*	*b*	*b*
CD	Uranium Enrichment	0.2	0.5	0.5	0.5
ST	Isotopes			23.8	22.3
Total		36.5	37.9	70.6	74.3
Percentage of total Laboratory funding—BA		8.2	8.1	12.7	11.9

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

Japan. A follow-on phase is possible beginning around FY 1993, during which ORNL will continue to provide assistance to the RETF and begin a return of 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, while 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 CFRP have provided the expertise and motivation for several robotics-related programs at ORNL that are now carried out in several divisions.

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 concept study provides a unique opportunity to compare U.S.-developed concepts with those proposed by experts in the United Kingdom who have designed the proposed European Reprocessing Demonstration Plant. The technical work in the design study is essentially completed; the final report will be completed early in FY 1990. Most of the R&D for the rad-hardening program was completed in FY 1989. The program will continue with design and data reviews through FY 1991 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 (Fig. 36) awaits a specific use to be identified. 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 Y-12 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.

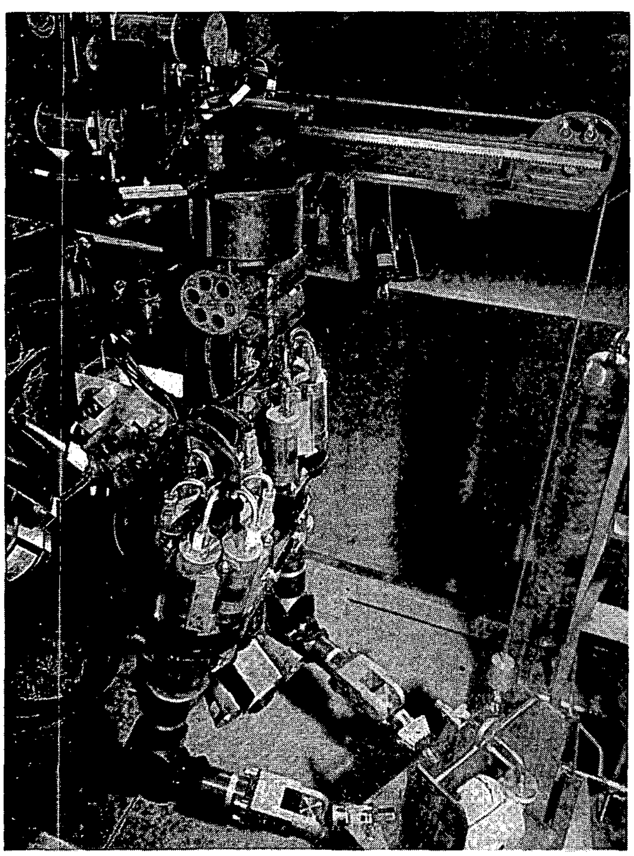


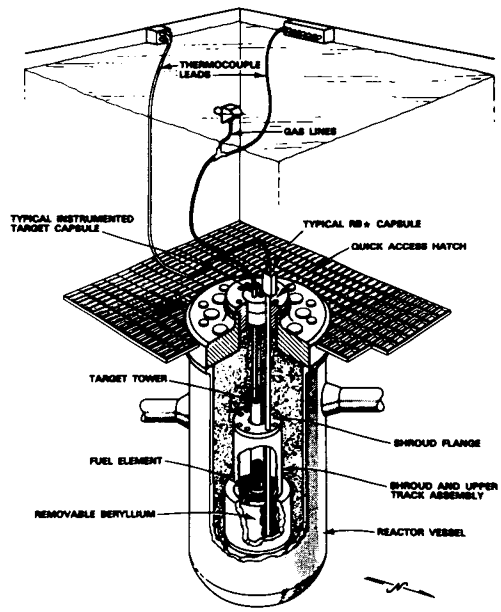
Fig. 36. The Advanced Servomanipulator, developed and built at ORNL, is the first servomanipulator of modular construction designed to be maintained totally by remote means. The dual-arm, bilateral force-reflecting master/slave manipulator incorporates advanced concepts in man-machine interface and digital control technology.

Reactor Program Improved light-water reactor (LWR) technology is an urgent national need to support improvements in performance and availability of current-generation LWRs as well as advanced concepts. Although the major portion of this effort will be carried out by industry, we expect to play a role in an expanded DOE LWR technology development program. Close cooperation with the Electric Power Research Institute (EPRI), the utility industry, and the nuclear power industry will be the basis for planning and implementing this effort. The developmental LWR program will focus on enhanced "passive" safety features for LWRs. Continuing LWR tasks include an annual update of the energy economic data base and production of engineering economic comparisons of nuclear options versus other energy sources. Activities are continuing in support of the EPRI advanced LWR plant requirements documents, advanced LWR control systems in cooperation with industry, and special studies, such as modeling and analysis related to the Chernobyl accident.

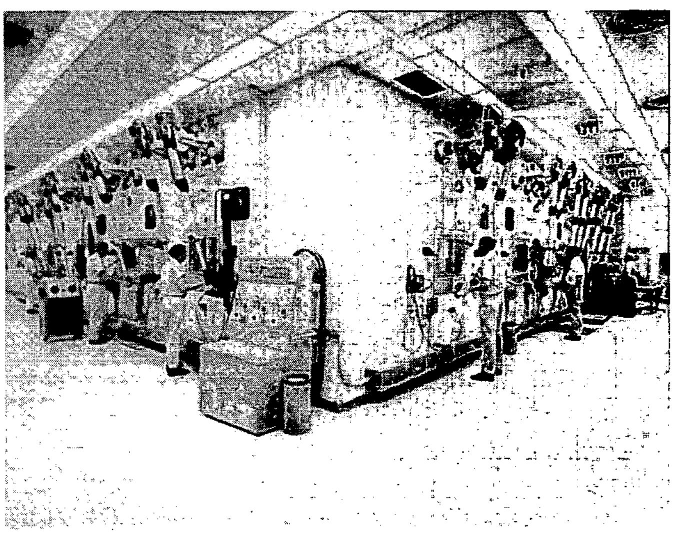
Primary emphasis in the national high-temperature gas-cooled reactor (HTGR) program is on development of a modular high-temperature gas-cooled reactor (MHTGR) (Fig. 37) using steel pressure vessels for the reactor core and steam generators in a side-by-side arrangement. ORNL has lead responsibility for the HTGR Base Technology Development Program. Technical activities include (1) performing qualification tests of HTGR fuel performance and fission-product behavior under postulated accident conditions; (2) providing basic data on the mechanical, physical, and chemical behavior of HTGR materials, including metals and graphite; (3) providing analytical evaluation of shielding designs; (4) performing safety analysis; and (5) providing technical and economic evaluations and assessments.

In the longer term, MHTGRs show promise of broadening the applications of nuclear power to high-temperature process heat areas and to electric power generation in water-limited regions. The

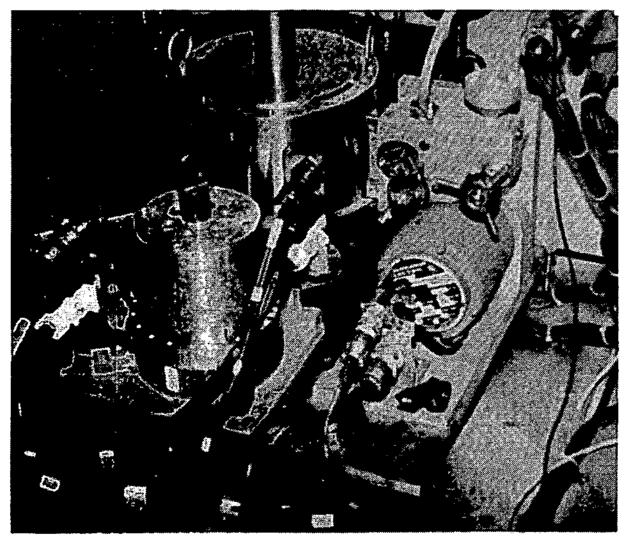
(a) The basic fuel unit is the coated particle.



(b) HFIR test facilities: Instrumented test capsules in dedicated facilities monitor in-reactor MHTGR fuel behavior.



(c) Hot cells: Remote examination facilities are available for full characterization of fuel behavior and fission product transport.



(d) IMGA system: Unique automated system characterizes fission product retention on statistically significant particle populations.

Fig. 37. MHTGR fuel and fission product research.

inherent safety features of the concept make it attractive for export to less-developed countries as well as for domestic applications.

Advanced Liquid Metal Reactor (ALMR) technology support will be focused principally on the base-technology areas of measurement and control, shielding, materials, structural design at elevated temperature, reliability, robotics, and safety. Emphasis is on tasks in support of a reference ALMR program.

Measurement and control activities will include man-machine integration, automated control methods employing artificial intelligence, and high-temperature fission counters and systems for automated surveillance and diagnostics. The Advanced Controls program will continue to be directed toward establishing a center for development and testing of advanced control and information-handling technology. This major activity will involve broad participation from both universities and industry.

Experiments at the Tower Shielding Facility will resume in a collaborative effort with the Japanese to investigate alternative shielding materials such as B4C for LMR near-core and deep-sodium environments. This collaborative effort should be completed in CY 1991. In addition, analytical and experimental support will be provided for the ALMR design. In materials and structural design, we will continue to develop and code-qualify the modified 9 Cr-1 Mo steel, provide improved design methods and criteria, and develop advanced in-service inspection techniques. General requirements for other materials such as stainless steels and 2¼Cr-1Mo will also be needed. The safety work will be concentrated in a joint program between the United States and Japan to develop a centralized, advanced reactor reliability data base and operate a reliability data-analysis center. R&D is under way with several university partners on a robotic system with the capability to autonomously perform maintenance, testing, and inspection tasks in hazardous environments.

Other general support tasks include Codes and Standards, Radiation Shielding Information Center, and the Energy Economic Data Base. Work on robotics for nuclear energy applications is described in other sections of this document.

Space Nuclear Power In the area of space nuclear power at ORNL, continued technical support is being provided 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 (CBCF) thermal insulators capable of effective operation at 1300°C. Production of these materials is anticipated in FY 1990, 1991, and 1992 in support of NASA's comet rendezvous asteroid flyby and Cassini missions. Since providing the hardware needed for NASA's Galileo and Ulysses missions in 1983, ORNL has maintained production capability and the inventory of iridium. In the interim, significant technical activities have been pursued. Specifically, (1) the process for producing CBCF with new starting materials has been optimized, (2) a new consumable arc melting process having the potential for fabricating iridium alloy hardware of superior metallurgical quality and lower cost has been developed, (3) improved nondestructive examination methods have been developed to support the manufacture of advanced thermoelectric elements and the iridium alloy blanks, and (4) efforts to qualify the Oak Ridge Y-12 Plant in the fabrication of iridium alloy clad-vent sets have been initiated.

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 (SP-100 Project) and in the multimegawatt range (MMW Space Power Program). In the ground engineering system 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 in the characterization of 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 Westinghouse-Hanford in FY 1993.

ORNL has served as the lead materials laboratory for the MMW program since 1984. Starting in FY 1990, two to three industrial organizations will be given full responsibility for the design and technology development of their respective concepts. ORNL is expected to serve a major role in providing technical support in the area of materials to each of the industrial organizations.

AH—Remedial Action Program

ORNL continues to play a major role in the DOE Remedial Action Programs (RAPs). 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 the Uranium Mill Tailings Remedial Action Project (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 (SFMP). 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 radiologically contaminated sites in the Formerly Utilized Sites Remedial Action Project (FUSRAP) and eastern SFMP sites. Rapid decline in UMTRAP funding and a slow, steady decline in the FUSRAP funding are anticipated over the next 4 years because of successful completion of ORNL milestones in these projects. SFMP funding is expected to increase significantly as the amount of decommissioning efforts at federal facilities increases.

CD—Uranium Enrichment

Martin Marietta Energy Systems, Inc., is engaged in a joint effort with the Lawrence Livermore National Laboratory (LLNL) to develop and demonstrate the Atomic Vapor Laser Isotope Separation (AVLIS) process for separating isotopes of uranium and other materials with finely tuned lasers. Energy Systems employees have had a significant role in the development of this process since the mid 1970s, but only in the last few years has there been a full consolidation of the LLNL and Energy Systems efforts. Currently, approximately 40 Energy Systems personnel are located on-site at LLNL in key programmatic positions. This effort at LLNL is expected to continue to grow over the next year as increasing programmatic effort is placed on the demonstration phase of the AVLIS development program.

Besides the effort at LLNL, some AVLIS development work has been performed at ORNL, including advanced materials development in the Metals and Ceramics Division and the uranium processing product demonstration in the Fuel Recycle Division. This work totals about $0.5 million for ORNL in FY 1989. The objective of the AVLIS materials development effort is to demonstrate performance for an operating separator. Over the next 3 years, the program will continue to establish a data base on extractor materials at prototypic conditions for anticipated operational lifetime. Physical/mechanical properties, wettability, stability, structural integrity, and materials compatibility are being determined using off-line and on-line test facilities. Energy Systems' efforts will be a part of the technology transfer to LLNL for performance demonstrations in its facility. Fuel Recycle Division uranium-processing efforts were directed toward assessing the technology and demonstrating at pilot-plant scale, as needed, the dissolution and purification by the Purex-type aqueous flowsheet and conversion of the uranyl nitrate powder to an oxide suitable for use in UO_2 production of reactor-grade UO_2. The Purex flowsheet, successfully employed in the nuclear fuel cycle process for over 40 years, offers the potential of a low-cost, technically attractive product processing option for the interface between AVLIS and fuel fabrication by private industry. Small-scale purification tests were completed in FY 1989; decisions have been made not to do larger demonstrations at this time. In FY 1989 initial plans for interaction with and support to the fabrication industry were developed.

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 on 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 industry where they are used for diagnostic and clinical procedures (Fig. 38). 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. After the HFIR restart is successfully achieved, the production of other research and medical radioisotopes will be resumed.

The shift of the isotopes activity into the Nuclear Energy Program represents a significant change. As part of this transition, the Isotopes

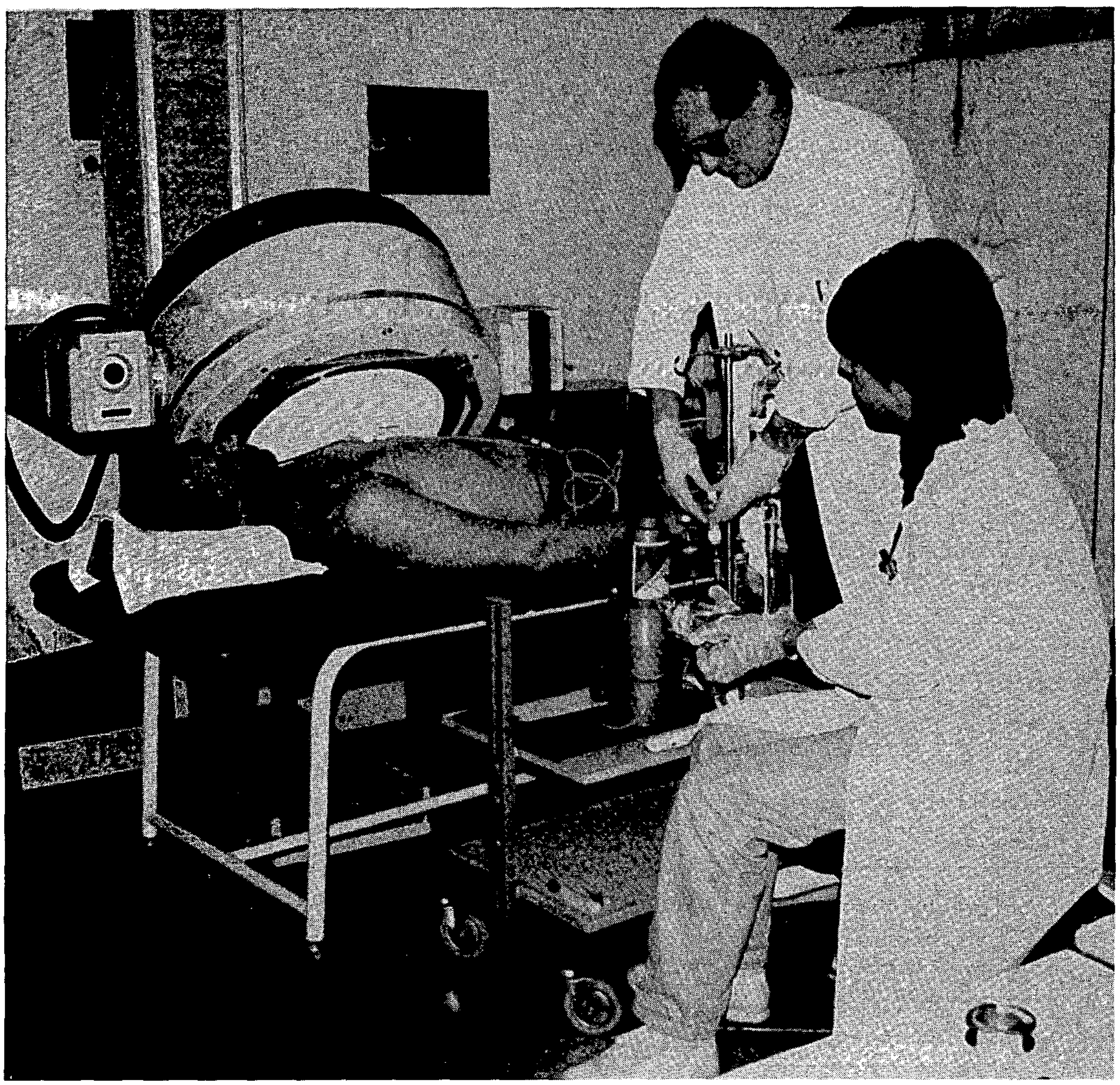


Fig. 38. Intravenous administration of iridium-191m for cardiac function research using a newly developed $^{191}Os/^{191m}Ir$ generator. Osmium-191 is produced by enrichment of ^{190}Os in the ORNL calutrons. The isotope is then irradiated in the High Flux Isotope Reactor, which has the unique capability of producing the large quantities and specific activity levels required for use in the generator. The generator was developed through a collaborative effort of researchers at ORNL and the University of Liege, Belgium.

Program will be established under a revolving-fund mechanism, requiring the program to rely on its sales revenues for funding. Restructuring of the Isotopes Program's business procedures will continue to occur to accommodate these program changes. An important issue for this program will be the funding requirements necessary to renovate the radiochemical processing facilities so as to meet, and maintain compliance with, current standards. This facility revitalization activity will continue to grow and emerge as a major program emphasis. The Modernization of the Isotopes Program is discussed in the Initiatives section of this document.

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 26). However, OCRWM is in the process of placing a large M&O contract, which is currently being challenged in litigation. If the contract is successfully placed, ORNL's role in support of OCRWM, particularly in the Waste Systems Data and Development Program, could be diminished.

DB—Nuclear Waste Fund

The repository component of the OCRWM program, which supports the ongoing geotechnical support tasks that have been redirected to contribute directly to and support the Yucca Mountain Project, was significantly reduced in FY 1989. The future of these tasks, which include geochemical studies and hydrologic model development and validation, is uncertain.

The transportation and system-integration component of the program supports three substantial 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 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 will 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.

Table 26. Office of Civilian Radioactive Waste Management major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
DB	Nuclear Waste Fund	9.1	10.3	11.8	12.4
DC	Civilian Radioactive Waste R&D	0.1	0	0	0
Total		9.2	10.3	11.8	12.4
Percentage of total Laboratory funding—BA		2.1	2.2	2.1	2.0

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

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. A new activity began in support of OCRWM in FY 1989. This work involves providing the staff function of a broad-based OCRWM strategic planning exercise. Initial efforts in this activity concentrated on the development of a planning process amenable to the particular OCRWM requirements. Activities in this area are expected to remain stable or grow modestly.

Assistant Secretary for Defense Programs

Programs sponsored by the Assistant Secretary for Defense Programs (DP) include Weapons Activities, Safeguards and Security, Materials Production, and Defense Waste and Transportation Management (Table 27). A significant new effort in this area involves technical assistance to the New Production Reactor (NPR)

Table 27. Assistant Secretary for Defense Programs major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
GB	Weapons Activities	1.5	1.7	2.1	0.7
GC	Verification and Control Technology	0.3	0	0	0
GD	Nuclear Safeguards and Security	0.6	0.7	0.6	0.7
GE	Materials Production	5.8	7.7	21.1	41.8
GF	Defense Waste and Environmental Restoration	26.7	30.8	53.8	44.7
Total		34.9	40.9	77.6	87.9
Percentage of total Laboratory funding—BA		7.8	8.8	14.0	14.0

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

Program. Another new activity is the Mark 42 Processing Program.

GB—Weapons Activities

A variety of tasks and projects are supported by Program GB, including some support provided 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 1989 and FY 1990 at $1.5 million per year. 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 LANL and LLNL. Large quantities of these materials are available at the Savannah River Plant in the form of irradiated target assemblies (Mark 42 targets) and raffinate solutions. Using the Radiochemical Engineering Development Center (REDC) at ORNL, the targets can be processed to recover the actinide elements. The first target will be processed in FY 1990. Because of this task and the NPR support activity, Program GB is expected to increase through FY 1990, with support remaining constant for the other tasks.

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 (HE). A very sensitive, small HE vapor detector is under development. A laboratory prototype was designed and constructed which is presently being field-tested.

GE—Materials Production

This program includes the ^{252}Cf Industrial Sales/Loans Program and the ^{233}U Storage and Distribution Program. A new major activity in Program GE is the technical support for the New Production Reactor Program, which is expected to increase significantly in the next 5 years. Another new activity is the Mark 42 Processing Program.

During FY 1988, DOE-DP conducted a study of reactor technologies for weapons-material production and evaluated candidate sites. In August 1988, the Secretary of Energy announced that DOE would build a heavy-water reactor (HWR) at Savannah River, South Carolina, and a four-module HTGR at Idaho Falls, Idaho. Preliminary schedules call for operation of the HWR in 1999 and operation of the MHTGR in 2004.

Considerable work needs to be done in licensing and technology development for the new production reactors. Energy Systems performed a preliminary-needs evaluation for the new production reactors and presented a capabilities statement to NPR project management. During the first quarter of FY 1989, the NPR project team reviewed and evaluated all capabilities statements submitted by national laboratories and industry.

As a result of this review and evaluation, ORNL was designated Lead Laboratory for Engineering Economic Analysis, Codes and Standards, and Program Support; and technology center of excellence for Materials and Instrumentation and Controls for both the HWR and MHTGR concepts and for Fuels and Fission Product Transport for the MHTGR.

For FY 1989 and FY 1990, the costs for the Mark 42 Processing Program will be divided between Programs GE and GB, for a total funding of $3 million per year. 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 Plant (SRP). These materials are to be used in weapons diagnostics at LANL and LLNL. The irradiated targets are shipped to Battelle Pacific Northwest Laboratories (PNL) 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 will begin in FY 1990. The funding supplements the Transuranium Element Processing Program funds, enabling maintenance of the REDC and meeting regulatory requirements without further significant needs for increased funds. Because massive funding for restart of the Multipurpose Plutonium Processing Facility at SRP is unlikely, the Mark 42 program at ORNL should continue for a number of years.

Other activities conducted under Program GE involve isotopes through the ^{252}Cf Industrial Sales/Loans Program and the ^{233}U Storage and Distribution Program. The Californium Industrial Sales/Loans Program was enhanced by a ^{252}Cf Users Workshop in Oak Ridge in April 1988. This 2-day workshop was attended by about 100 people, including DOE, DOD, and commercial users, both domestic and foreign. The ORNL 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, are being placed in standby condition by 1989. Safeguarded storage of ^{233}U in the RPP will be continued. A conceptual design is available for installing new ^{233}U processing facilities with significantly improved capabilities should DOE's needs for purification of ^{233}U be renewed. The new facilities would be located in two of the shielded cells at the REDC.

GF—Defense Waste and Transportation Management

ORNL performs research, development, and demonstration activities for the GF Program on radioactive, mixed, and hazardous wastes, primarily for the Hazardous Waste Remedial Action Program (HAZWRAP) lead office. Examples of R&D projects include (1) development of field analytical methods constituents, (2) bioremediation of mercury contamination, (3) sensitivity and uncertainty analysis of performance codes for LLW disposal, and (4) bioremediation of polychlorinated biphenyl (PCB) contamination. Demonstrations supported under this program include volume reduction and treatment of hazardous and mixed waste and methods for removing volatile organic carbons from groundwater. This area is expected to grow significantly over the next few years as DOE-DP expands its efforts to address waste management issues at Defense Program facilities.

ORNL activities for the DOE-DP also encompass management of low-level and transuranic (TRU) wastes as well as ORNL site remedial actions.

Both solid and liquid low-level wastes (LLW) 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 should be operational by the early 1990s. Storage and disposal techniques for providing greater confinement are used for all solid LLW. A tumulus-based demonstration is proceeding. 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 an emergency avoidance solidification campaign for solidifying 50,000 gal of liquid LLW as cement-based waste that will be stored at ORNL pending further evaluation of disposal options. This operation, which began September 28, 1988, and was completed December 23, 1988, restored some operational flexibility to the liquid LLW system (Fig. 39).
- 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 scheduled to begin during September 1989.
- Processing in the Waste Handling and Packaging Plant (WHPP), discussed below, to convert TRU sludges and associated liquid waste currently in the storage tanks to a solid, remotely handled TRU waste that will be disposed of in the Waste Isolation Pilot Plant (WIPP) located near Carlsbad, New Mexico.

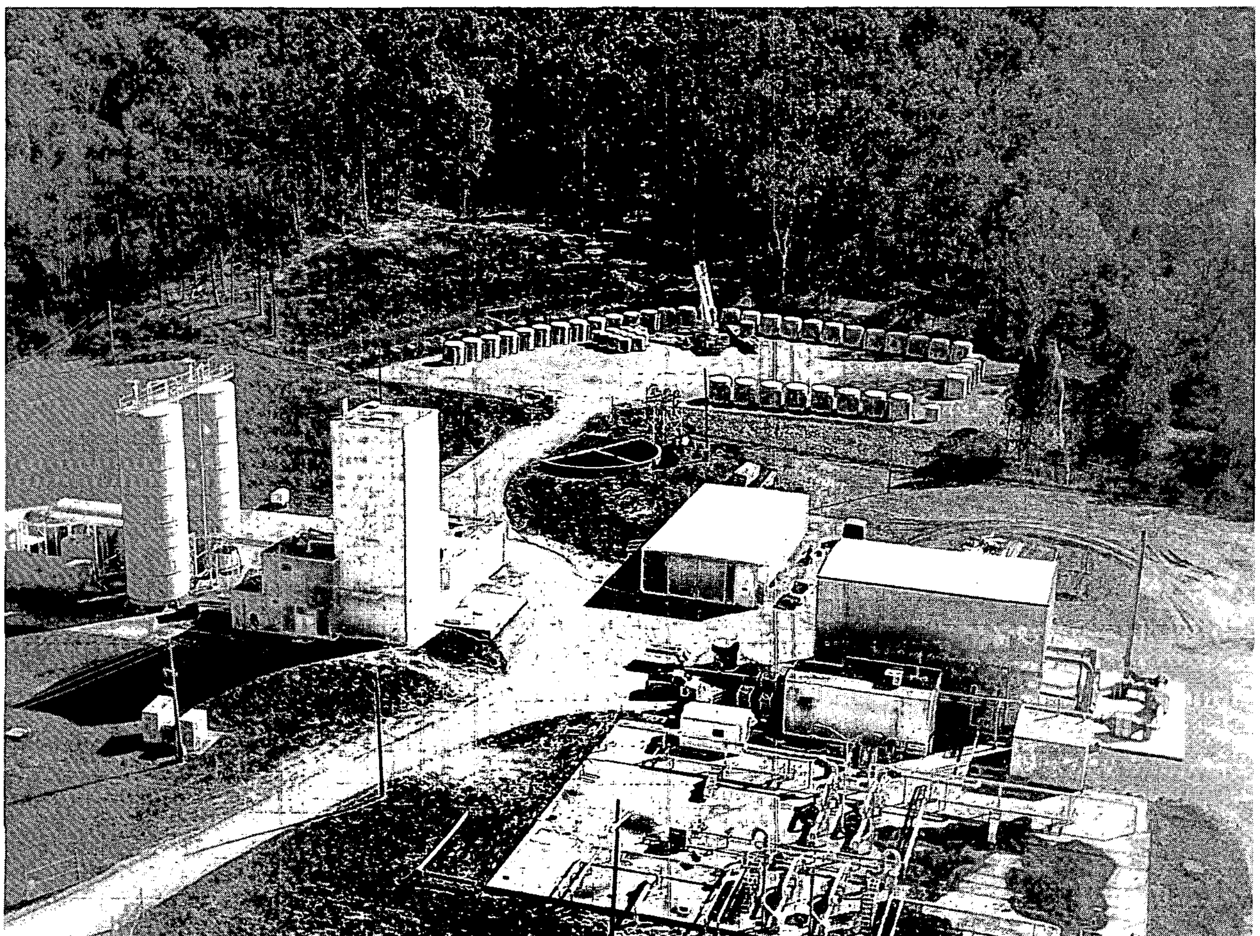


Fig. 39. During the first quarter of FY 1989, nearly 50,000 gal of liquid radioactive waste was removed from underground storage tanks (lower right), solidified using cement technology (in the large building on the right), and placed in concrete casks in aboveground storage (background). The space freed in the storage tanks was needed for storage of additional research-generated wastes, as well as to provide contingency storage to accommodate waste generated from emergency scenarios. A subcontractor, LN Technologies, Inc., of Columbia, South Carolina, installed and operated a mobile LLLW solidification system placed inside ORNL facilities. The solidified waste will be held and monitored by ORNL personnel for up to 5 years, while DOE determines the final disposal destination.

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 transuranic (TRU) waste: contact handled (CH) and remotely handled (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 has completed examination of its stored CH TRU waste, and about 50% of the drums met the certification requirements. Further work will be necessary before the remaining 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 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 Waste Handling and Packaging Plant, is proposed as an FY 1993 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 area (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-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 a comprehensive remedial investigations/feasibility study for characterizing SWSA 6 and evaluating the resulting data, interim closure of the Resource Conservation and Recovery Act (RCRA) storage units within SWSA 6, planning and technology demonstration for underground tank closure, and 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 28). 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.

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 Microwave Sintering of Ceramics, derive 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 funding for Program ED is in expectation that the steel initiative, the continuous fiber ceramic matrix composites initiative, and other ceramics development will entail increased activity. The decrease in funding for Program EE after FY 1990 reflects scheduled completion of tasks under Ceramic Technology for Advanced Heat Engines.

Table 28. Assistant Secretary for Conservation and Renewable Energy major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
AK	Electric Energy Systems	3.1	4.6	7.0	9.5
AL	Energy Storage Systems	0.9	1.0	0.8	0.8
AM	Geothermal Energy	0.1	0	0.1	0.1
CE	Hydropower	0	*b*	0.3	0.4
EB	Solar Energy	3.3	2.9	4.1	4.2
EC	Building and Community Services	10.8	10.2	11.4	11.5
ED	Industrial Energy Conservation	2.2	2.3	3.2	2.9
EE	Transportation	17.5	20.2	21.8	20.7
EF	State and Local Programs	0.4	0.3	0.3	0.4
EG	Multisector	6.2	5.3	4.8	5.3
Total		44.5	46.8	53.8	55.8
Percentage of total Laboratory funding—BA		10.0	10.0	9.7	8.9

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

[b]Less than $0.1 million.

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 there was growing recognition of the need to find more effective mechanisms for government and industry to work together. These two needs have led to the creation of High-Temperature Superconductivity Pilot Centers at ORNL, LANL, and ANL. 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.

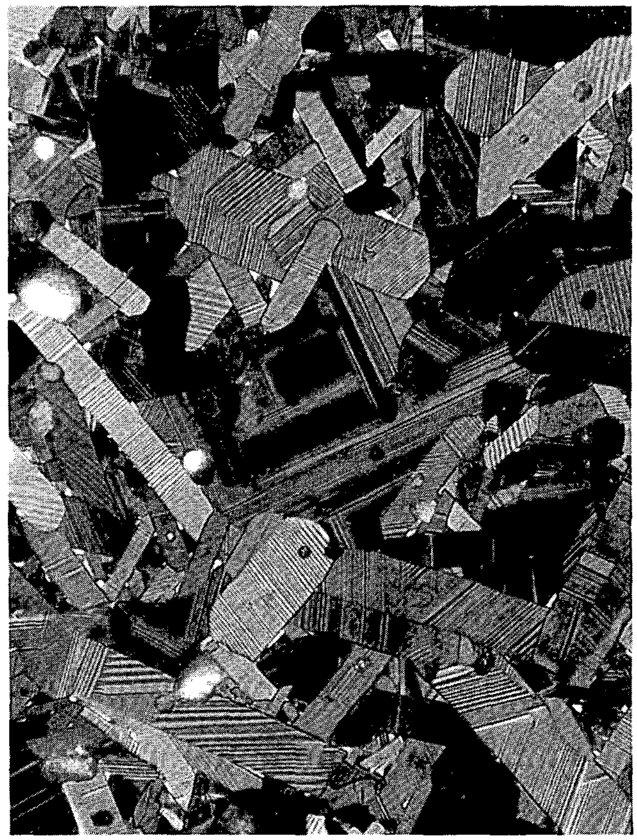


Fig. 40. Microscopic image of a polished cross section of sintered $YBa_2Cu_3O_{7-x}$ in polarized light showing grain morphology, grain size, and porosity.

A second, closely related project is ORNL participation in the Superconducting Technology for Electric Power Systems (STEPS) 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. During FY 1989 the project showed that very small grain sizes, on the order of 1 μm (Fig. 40), are needed to prevent formation of microcracks, and that precisely controlled composition is an important variable.

In other Electric Energy Systems work during FY 1989, a report was prepared summarizing several years' work on the identification of promising new polymers for electrical insulation and determination of their properties during aging. A new 5-year program plan was prepared on dielectric and magnetic materials. In a follow-up to the highly successful Athens Automation and Control project, the System Reconfiguration and Analysis Program (SYSRAP) was installed and implemented at the Athens Utility Board. This program uses real-time data from the distribution system to update the utility's data base for operations.

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.

AM—Geothermal

ORNL's activity in Program AM is research on the chemistry of geothermal systems. During FY 1989, measurements of the solubility of gibbsite [$Al(OH_3)$] were extended to consideration of the effects of sulfate and sulfite concentrations. These results will be used to model the development of scaling formed during geothermal extraction and reinjection. This research is expected to continue in future years.

CE—Hydropower

ORNL has been responsible for the environmental subprogram of DOE's Small Hydro Program, conducting research on key environmental problems affecting the hydroelectric industry. In FY 1990, research will focus on a critical review of monitoring and mitigation practices in licensing nonfederal hydroelectric projects. The feasibility of fish population models for instream flow assessments and cumulative impact analysis will be evaluated.

EB—Solar Energy

ORNL has been assigned field-management responsibility for biomass production. The goal of this work is to develop competitive specialized terrestrial energy crops for conversion to gaseous and liquid fuels. Interdisciplinary research is conducted in the fields of biotechnology, physiology, genetics, and new energy crop husbandry (Fig. 41). Much of this research is subcontracted to research stations situated so as to investigate crop-production rates in various climates and soil conditions.

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 are being identified to focus research on the most relevant topics. ORNL will participate in multiyear planning efforts coordinated by DOE. Private-sector cost sharing is strongly encouraged in subcontracted research efforts.

During FY 1988 the global climate change [carbon dioxide (CO_2)] issue emerged as an important additional incentive for 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.

Both herbaceous and woody biomass production continue to approach the economic targets of being competitive with coal as the research yields more complete data on species selection and optimal cultural conditions. For instance, data from Purdue University showed high yields from some herbaceous species even

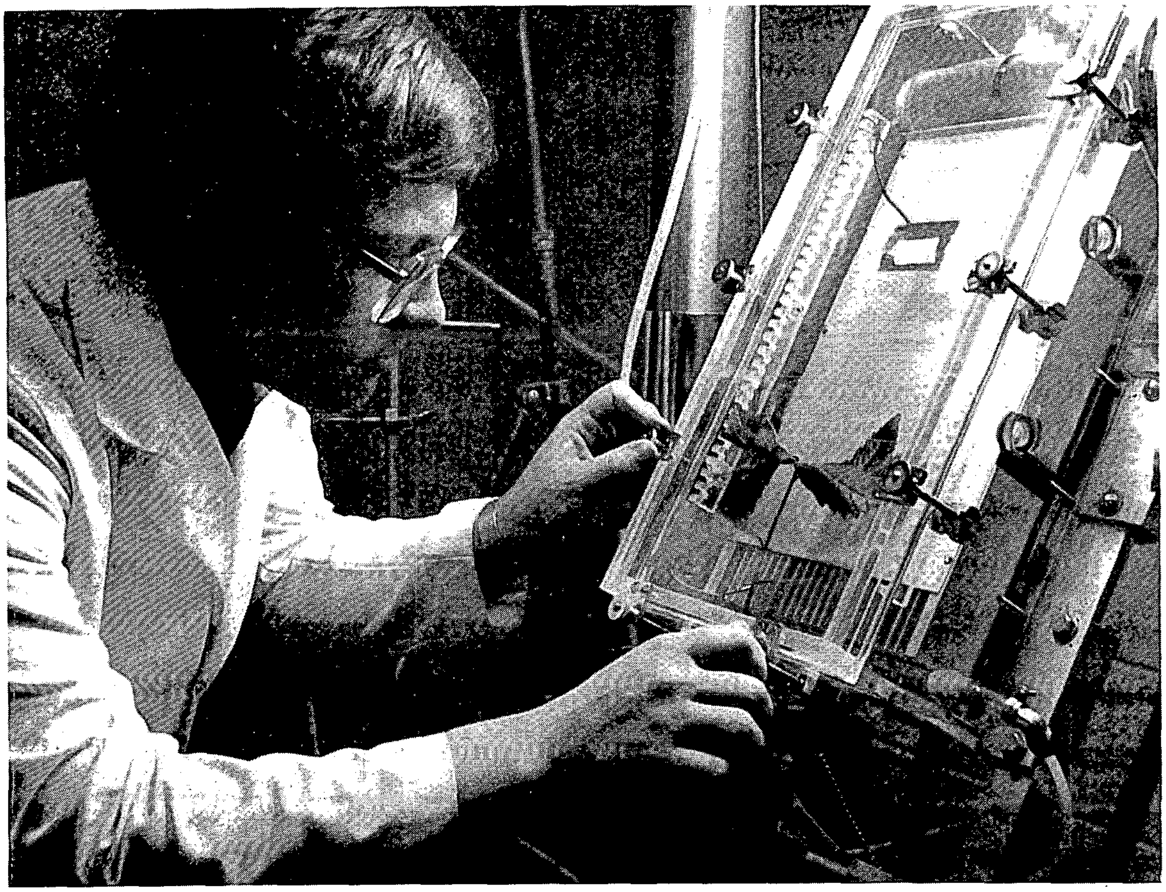


Fig. 41. Environmental scientist, Paul Hanson, places tree seedlings in a Siemans-Siragor apparatus to measure plant photosynthesis and respiration under various light conditions.

under the unfavorable drought conditions in the summer of 1988.

Research is expected to continue during the planning period with steady progress toward the ultimate goal of economic fuel production.

ORNL participation in the Solar Energy Program also includes planning activities in the Integrated Electric Utility Program for lesser-developed countries and environmental assistance to the Office of Alcohol Fuels.

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 1988 the Council of American Building Officials adopted ORNL recommendations for foundation insulation levels and for assigning thermal mass credits into the 1989 Model Energy Code (MEC). This step is significant because the MEC is frequently cited in local building codes.

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 chlorinated fluorocarbons (CFCs) as working fluids. The international agreement (the "Montreal Accord") to limit worldwide use of CFCs has increased the urgency of this task. During FY 1989 a number of meetings were held with EPA, DOE, and appliance manufacturers to coordinate the work. An initial screening of potential substitutes was made, and laboratory tests were conducted on several nonazeotropic CFC mixtures. 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) (Fig. 42) 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. During FY 1989, the triple-effect absorption chiller was licensed to the Trane Company. Successful commercialization by Trane and The Gas Research Institute (GRI) could give the United States a multibillion-dollar worldwide market in cooling systems for commercial buildings. It is expected that funding for electric heat pumps will decline in the future as current tasks are completed, while funding for heat-actuated systems may increase.

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.

Fig. 42. Robert DeVault shows a computer model of the triple-effect absorption chiller he invented. The gas-fired heat pump was designed for cooling large buildings.

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 was completed at ORNL during FY 1989 and is being used to 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 started in FY 1989 to determine the extent of industrial needs for new technologies in continuous fiber ceramic matrix composites. This task will produce a 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 developing continuous chromatography as a method for separating multiple components from aqueous solutions in a single unit (e.g., mixtures of sugars or mixtures of metallic ores). Another project, the development of corrosion-resistant materials for use in molten nitrate-nitrite salts, has identified iron aluminide as a particularly 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 Steel Initiative.

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 three projects in transportation: Ceramic Technology for Advanced Heat Engines, HTML user centers, and Alternative Fuels Utilization.

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. 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 recent achievements was the development of high-frequency ultrasonic-wave-imaging inspection such that defects as small as 25 μm could be detected in ceramic specimens. This accomplishment is very important in that the critical flaws causing failures in ceramics are often as small as 25 to 50 μm and cannot be detected reliably by conventional techniques. Another development was confirmation that, with small amounts of additives, it is possible to use microwave energy to sinter silicon nitride (an ORNL initiative). In accordance with the multiyear plan, the level of effort on this project is expected to peak during FY 1989 and 1990 and decline sharply in subsequent years.

The HTML was completed in FY 1987. This facility houses laboratories and special equipment to support the Office of Transportation Systems, other DOE offices, universities, and industry in advanced materials research (Fig. 43). Four user centers are operated within the HTML, with funding designated for this purpose. At the end of FY 1988, 25 user agreements had been established with U.S. universities and industry. An increased funding level is expected for this project.

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. In research subcontracted

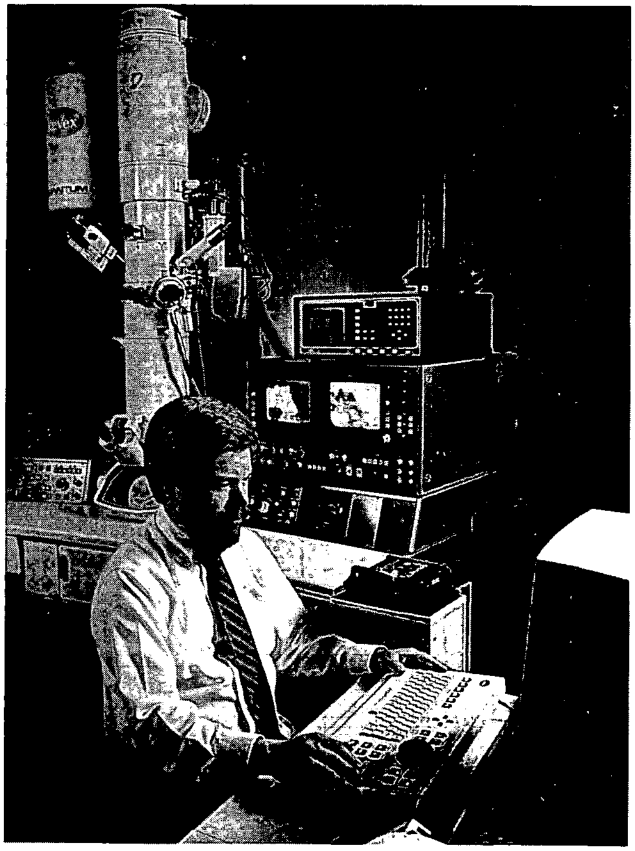


Fig. 43. Larry Allard is operating the JEOL 2000FX analytical electron microscope in the High Temperature Materials Laboratory. This microscope is being used to determine the crystal structure of high-temperature ceramics as a part of the Ceramic Technology for Advanced Heat Engines project and as a part of the HTML user program, both sponsored by the Office of Transportation Systems.

to Pennsylvania State University, recent results show that fuel chemistry has substantially less effect on diesel engine emissions than do other major parameters that are used to characterize the combustion process. Very likely, only heavy aromatics have any significant effect on emissions. In other work, the methanol fleet demonstration has completed nearly 1,000,000 miles at the three participating laboratories: LBL, ANL, and ORNL. No major technical problems have been encountered, and driver acceptance has been good. 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.

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

ORNL assists DOE in evaluating the effectiveness of several of the grant programs. This work is closely coordinated with the Existing Buildings Research project under the EC Program. Continuation is contingent on the extent of future Congressional appropriations.

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 (Fig. 44). 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 1989 numerous developments were successfully completed in ECUT Materials, including the first ductile Ni_3Al alloy that can be used for castings. The castable form will greatly increase the usefulness of the material to potential users, such as Cummins Engine Company. Another ECUT Materials task was the

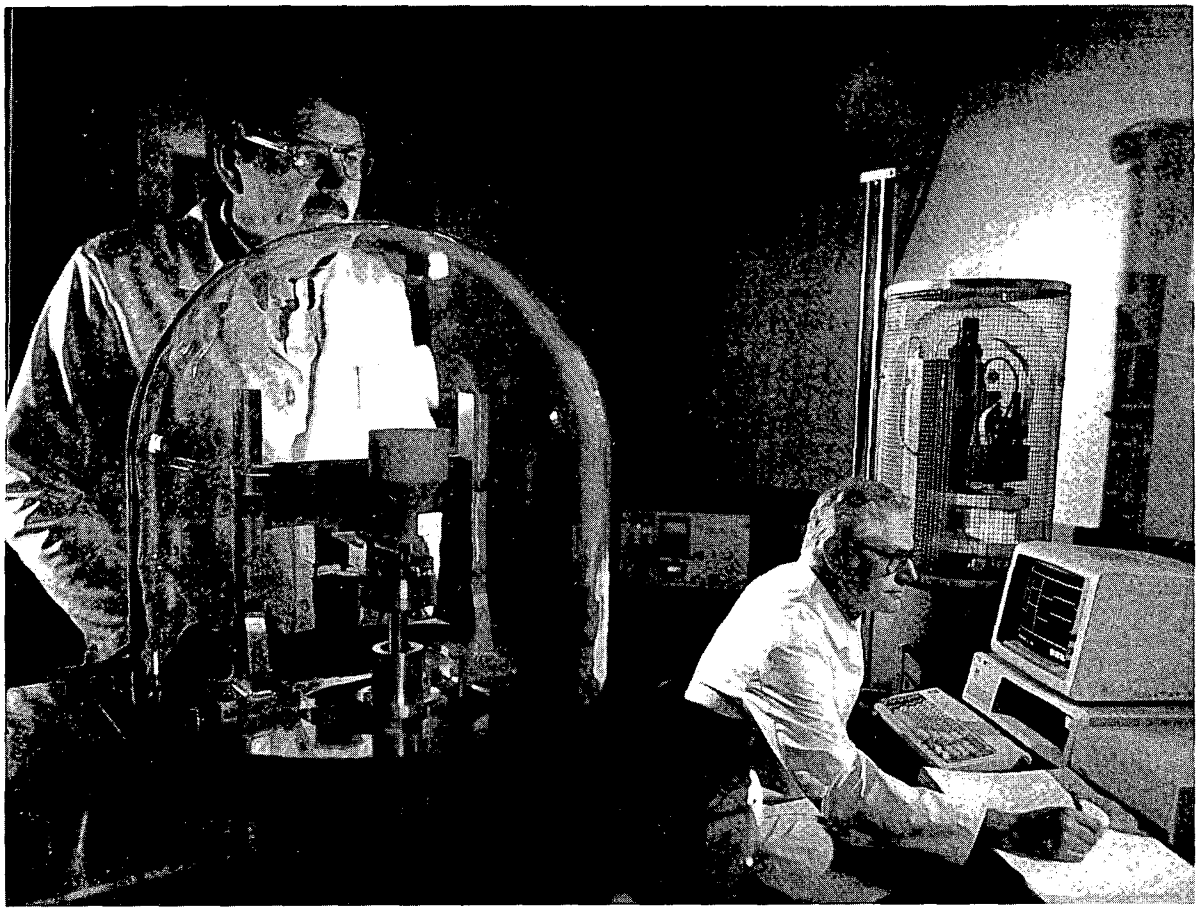


Fig. 44. Charles E. DeVore and Charles S. Yust, researchers from ORNL's Metals and Ceramics Division, use computer-controlled friction and wear testing at high temperatures and in controlled environments to evaluate the potential of ceramics and composites as future bearing materials. A room-temperature friction and wear test system is under the glass bubble in the foreground; the high-temperature friction and wear test system is contained in the wire cage on the right-hand side of the photograph.

development of a high-temperature effusion cell for the production of new materials. Multilayered ceramics have been produced, and application to high-temperature superconductors (an ORNL initiative) has begun. The effusion cell will enable the design of a new class of ceramic materials with unique properties. In the Tribology project the first investigation of the tribological properties of Y-Ba-Cu-O superconductors was published as an ORNL technical memorandum. These data include sliding friction coefficients, indentation hardness, abrasion data, scratch tests, and elastic modulus by indentation. 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. The evaluations consider both the effectiveness of the project in helping inventors to commercialize their ideas and the extent of resulting energy savings.

Assistant Secretary for Fossil Energy

ORNL programs for the Assistant Secretary for Fossil Energy (FE) cover the following areas: coal, gas, petroleum, clean coal technology, strategic petroleum reserve, alternate fuels production, and support to the DOE energy technology centers. The principal focus of the Laboratory's fossil energy activities, however, is coal. The coal budget is anticipated to remain approximately level, with primary emphasis on materials; bioprocessing of coal; and environmental, health, and safety (EH&S) research (Table 29).

AA—Coal

Materials research activities, including management (with DOE-ORO) of the Fossil Energy Advanced Research and Technology Development (AR&TD) Materials Program, comprise the major portion of the Coal budget at ORNL. It is expected that the materials effort of the Fossil Energy Program will proceed at approximately the same level and in the same areas of emphasis over the next 5 years.

Fiber-reinforced ceramic composites with improved strength and toughness are being produced by the chemical-vapor infiltration and deposition (CVI) 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 (Fig. 45). In the CVI process, reactant gases are passed through a ceramic fiber body and reacted to form a ceramic matrix that is bonded to the ceramic fibers. Ceramic fiber–ceramic matrix composites fabricated by the CVI process can be made in a variety of shapes and sizes. In addition, the ability to control the porosity of a composite means that both highly dense composites (for purely structural proposes) and porous composites (for filter applications) can be fabricated. Ceramic membranes for the separation of gases in high-temperature and hostile environments are also being developed and tested. Other work on ceramics is devoted to the microwave sintering of ceramics. The application of this technology will be for 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 superheaters and reheaters for

Table 29. Assistant Secretary for Fossil Energy major program summary[a]
[$ in millions-budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
AA	Coal	5.9	5.8	5.9	6.1
AN	Energy Technology Center Program Direction	0.1	0	0.2	0.2
AZ	Innovative Clean Coal Technology	0.5	1.1	0.4	0.7
SA	Strategic Petroleum Reserve	0.3	0.3	0.4	0.4
Total		6.8	7.2	6.9	7.4
Percentage of total Laboratory funding—BA		1.5	1.5	1.2	1.2

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

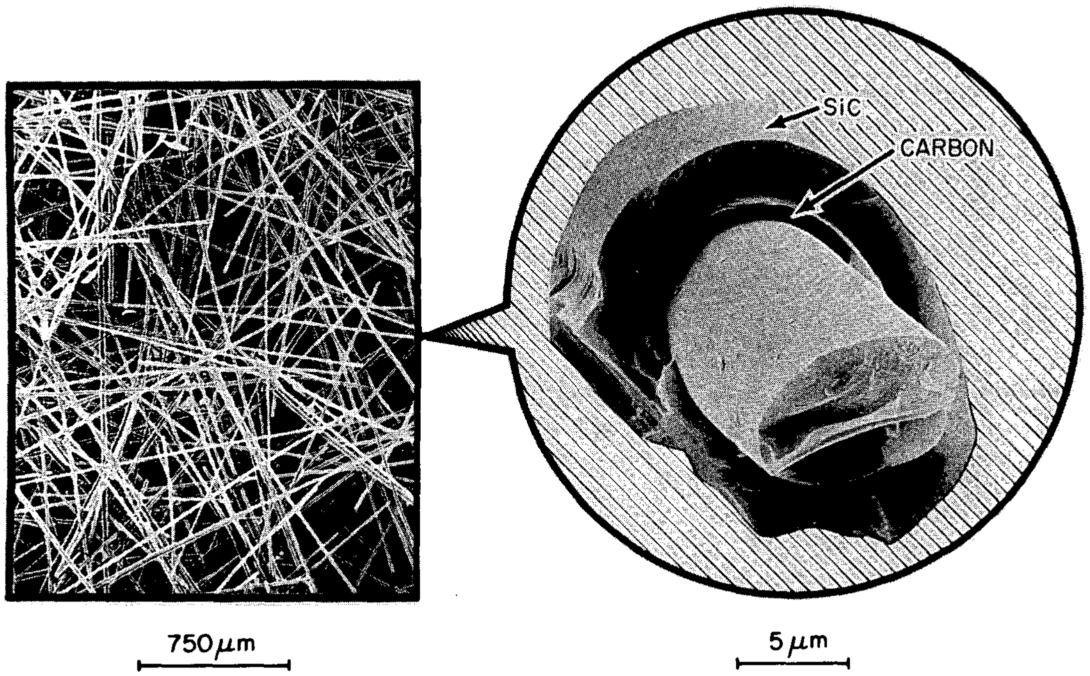


Fig. 45. Silicon carbide felt filter coated with a chemical-vapor deposit of pyrolytic carbon and SiC. These ceramic composite filters are being developed for use in hot-gas cleanup systems.

fluidized-bed or pulverized-coal combustion. The objective of this work is to modify existing alloys and to develop new alloys that will satisfy the strength and corrosion-resistance requirements of high-temperature, high-pressure, second-generation power plants. Intermetallic alloys based on Fe_3Al are also being developed for applications in which superior corrosion resistance and strength are required. The work on iron aluminides has been expanded to address the improvement of room-temperature ductility, and the focus in the next several years will be on achieving properties that will meet performance criteria for specific industrial applications. The important implications of the use of iron aluminides are cost reductions and improved corrosion resistance in the sulfur-bearing atmospheres typical of coal-conversion and utilization systems. Current materials and designs for tubesheets and manifolds for hot-gas filter systems are also being examined, with the aim to recommend a tubesheet material suitable for long-term operation of these systems.

Basic studies of erosion and corrosion are being conducted to develop a fundamental understanding of these processes and of the relationship of materials properties to resistance to degradation by erosion and corrosion. 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. Corrosion research at ORNL centers on studies of the formation and breakdown of protective oxide scales, particularly in sulfur-containing atmospheres. The goal of this work is to understand the composition and characteristics of alloys that are necessary for the formation of adherent protective oxide films and scales.

Assessments of materials problems and the needed research to solve those problems for a variety of fossil energy technologies is an important part of ORNL's materials effort. In addition, ORNL has a commitment to transfer the technology developed in the Fossil Energy Materials Program to others in the fossil energy community. A recent example is the formation of the Thermomechanical Model Software Development Center (a consortium of 12 industrial organizations and ORNL) for the development of user-friendly, intelligent software for the thermomechanical stress analysis of refractory systems. The software is based on a complex computer model developed on the AR&TD Materials Program.

Coal-conversion work at ORNL involves bioprocessing of coal and the evaluation of coal-derived liquids produced by mild gasification processes. Evaluation of the coal liquids includes physical, chemical, and combustion properties. The bioprocessing of coal is being explored through the use of microorganisms to convert coal into useful liquid products. Bioreactor concepts that maximize coal solubilization and product yields are being examined. Bioprocessing of coal will continue to be an important part of the Fossil Energy Program during the coming years, and the plans for this area are described in more detail in the Initiatives section of this document. 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. The implication of the coal-conversion research will be the development of techniques and processes to minimize the effects of acid rain and related environmental impacts.

The ORNL Fossil Energy Program provides EH&S support to DOE for synthetic fuels plants by reviewing required documentation for the operation of the plants and by developing data bases and information systems for the compilation of critical environmental information. Activities supporting the synthetic fuels plants will decline over the next several years as ownership of the plants is transferred to private industry. Environmental support is also provided to DOE in the documentation on the effects of acid rain and CO_2. We expect that this activity will continue to be an important part of the Fossil Energy Program because of the need to concentrate on the clean use of fossil fuels.

The ORNL Fossil Energy Program is involved in the modeling of fuel supplies and market penetration. A family of computer models of liquid and gaseous fuel supplies has been developed that can be used to analyze the impacts of various policy issues, such as offshore leasing policies, on domestic supplies, and to forecast the replacement costs of domestic crude oil. The models can also be used to plan future research directions so they are compatible with current trends in technology and the marketplace and to analyze the effect of the market penetration of synthetic fuels and unconventional oil and gas technologies. This activity will likely remain fairly constant over the next 5 years as our knowledge of oil reserves and exploration is revised and updated.

AN—Energy Technology Center Program Direction

Material Safety Data Sheets are provided to the Pittsburgh Energy Technology Center (PETC) to support the development of occupational safety and health programs at PETC. Beginning in FY 1989, ORNL is providing technical support to PETC in the implementation of coal projects as part of a joint venture between PETC, the government of India, and the U.S. Agency for International Development.

AZ—Innovative Clean Coal Technology

Work on the Clean Coal Program (CCP) includes support in the areas of environment, materials, and information management. The CCP is an important new initiative that is jointly funded by DOE and industrial organizations. Two solicitations involving 29 projects have been completed by DOE, and a third solicitation was initiated during FY 1989. Fourth and fifth solicitations for the Clean Coal Program are planned for future years. This $2.75-billion program is an important potential funding source for ORNL over the next several years.

ORNL began providing support to the CCP with a modest level of funding in late FY 1986. An important part of our involvement on the CCP is environmental technical support to DOE in the preparation of National Environmental Policy Act (NEPA) reviews of site-specific projects. ORNL staff also assisted in the preparation of a Programmatic Environmental Impact Analysis (PEIA) for the second solicitation of the CCP. The PEIA, completed in September 1988, examined the impacts of commercialization of the technologies to be demonstrated in the second solicitation of the CCP, and it has been used in the selection of demonstration projects. A Draft Programmatic Environmental Impact Statement (PEIS), completed by ORNL staff in June 1989, covers all solicitations of the Clean Coal Program. Materials failure analyses, a significant factor in the success of advanced clean coal technologies, have been conducted for the Pittsburgh Energy Technology Center (PETC) since FY 1988.

Support for the CCP has grown to over $1 million in FY 1989. Work at ORNL now includes materials work for PETC and environmental work for DOE headquarters, PETC, and the Morgantown Energy Technology Center (METC).

CH—Alternate Fuels Production

Materials technical support has been provided to DOE in the operation of the Great Plains Coal Gasification Plant. With the recent sale of the Great Plains Plant to private industry, work in this area is being phased out.

SA—Strategic Petroleum Reserve

ORNL is performing work for the Strategic Petroleum Reserve (SPR) Program in two main areas. One task is concerned with the development of a baseline data set for specific metals and organic chlorine in a variety of whole crude oils and in distillate fractions from those crude oils. The second task is to assist in the assessment of alternative methods of financing oil acquisition and models for the drawdown of the Strategic Petroleum Reserve. It is expected that SPR support activities will continue at about the same level in the next 5 years.

Assistant Secretary for Environment, Safety, and Health

ORNL work for the Assistant Secretary for Environment, Safety, and Health (EH) includes development of environmental policy assessment methodologies and models, application of these to analysis of proposed and existing environmental legislation and regulation, and planning and assessment of technologies for dealing with radiological emergencies (Table 30).

HA—Overview and Assessment

ORNL continues to provide technical support to the Office of Environmental Guidance and to the Office of the NEPA Project Assistance. There is no anticipated change in these activities. ORNL's technical support to the Office of Environmental Guidance includes analysis of regulations being promulgated by EPA under RCRA; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); the Safe Drinking Water Act; and other environmental compliance statutes. ORNL staff track and evaluate regulatory initiatives under these statutes and help develop and disseminate

Table 30. Assistant Secretary for Environment, Safety, and Health major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
HA	Overview and Assessment	8.2	7.9	7.1	7.6
Percentage of total Laboratory funding—BA		1.8	1.7	1.3	1.2

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

guidance to facilitate achievement and maintenance of environmental compliance by DOE headquarters and field organizations. Our long-term support to the Office of NEPA Project Assistance continues with a major initiative of providing technical support for evaluating and improving compliance with NEPA at all DOE facilities.

For 14 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 policy issues. This support will continue with increased attention to acidic deposition issues and to the potential effects of global trace-gas emissions. OEA is funding a variety of projects, including a flue-gas desulfurization information system, a study of landscape and lake acidification relationships, a pilot study of the application of expert systems to OEA problems, an evaluation of the status and extent of acidic deposition effects on Canadian surface waters in relation to the needs of the National Acid Precipitation Assessment Program (NAPAP) 1990 Report, 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.

Sponsors of the Emergency Technology Program (ETP) plan to increase the research component 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 will terminate in early 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 31).

Table 31. Energy Information Administration major program summary[a]
[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
TA	Collection, Production, and Analysis	1.1	1.6	1.5	1.9
Percentage of total Laboratory funding—BA		0.2	0.3	0.3	0.3

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

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 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 operations offices (Table 32).

Assistant Secretary for Management and Administration

ORNL does a small amount of work for the Assistant Secretary for Management and Administration under two budget and reporting codes: WB and WM. WM program involves assisting the independent cost-estimating (ICE) staff of the Office of Project and Facilities Management, in projecting life-cycle costs of nuclear weapons. WB program covers an in-house energy management activity.

WB—In-House Energy Management ORNL is conducting energy conservation studies in laboratory facilities to achieve the energy consumption and efficiency goals established in its 10-year energy-management plan. The following tasks are included: variable-flow fume hood study, direct digital control systems for research facilities, and steam distribution system.

WM—Services The WM program involves assisting the ICE staff of the Office of Project and Facilities Management, DOE headquarters, in estimating life-cycle costs of nuclear weapons that are currently under development. Estimating life-cycle costs involves developing cost-estimating relationships for developing, testing, producing, maintaining, evaluating, and disposing of weapons. Production cost uncertainties must also be studied to provide a

Table 32. Other DOE programs and installations[a]
[$ in millions—budget authorization (BA)]

	Fiscal year			
	1988	1989	1990	1991
Assistant Secretary for Management and Administration	0.4	0.1	0.2	0.2
Office of Policy, Planning, and Analysis	0.2	0.4	0.3	0.3
DOE contractors and operations offices[b]	14.1	29.3	17.8	12.3

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

[b]CIT funding from Princeton Plasma Physics Laboratory is reported under Program AT.

method to determine confidence intervals of future weapons-cost estimates.

Office of Policy, Planning, and Analysis

Work for the Office of Planning and Analysis (PE) will include research on transportation, energy efficiency, and alternative fuels, especially automation 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 lead role in developing the National Energy Strategy.

Other DOE Organizations

In addition to the DOE organizations explicitly identified in this section, 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 3% 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 artificial intelligence and power systems by developing an expert-system prototype to process Bonneville's microwave communication system alarms.

Other ORNL Programs

Robotics and Intelligent Systems Program

The Robotics and Intelligent Systems Program (RISP) at ORNL builds upon the Consolidated Fuel Reprocessing Program's development and demonstration of remote technology and the basic research efforts of the Center for Engineering Systems Advanced Research (CESAR). RISP is a focal point at ORNL for studies in robotics, teleoperations, and related aspects of intelligent machines, such as artificial intelligence, neural networks, and parallel computing. The program is interdisciplinary and uses the expertise of scientists and engineers from several research and support divisions at ORNL. RISP conducts research for DOE, DOD, NASA, and other sponsors.

The goals of RISP research are to (1) minimize human error through automation of repetitive, dull, and routine tasks; (2) minimize human risk by allowing effective remote operation in hazardous environments; (3) optimize effective human-machine interactions; and (4) cope effectively with emergency situations requiring fast response. The context is often one of unstructured, dynamic environments and includes unexpected events and multiple participating agents. This requires developing the capability for flexible and efficient operation in the face of unknown or uncertain events and partial information while accommodating externally imposed time constraints. The research includes developing an appropriate combination of teleoperation and autonomous operation to achieve the necessary level of technological performance.

RISP's wide range of basic R&D programs includes those sponsored by federal agencies, many of which are conducted in collaboration with university researchers.

Among these programs are research in intelligent machines for DOE's Office of Basic Energy Sciences Engineering Research Program (DOE-BES-ERP) and development of robots to perform surveillance and manipulation functions within a nuclear plant for DOE-NE. Another effort focuses on remote technology development derived from ongoing research in teleoperated remote maintenance and repair for the nuclear fuel reprocessing program (a DOE-NE-Japanese collaboration). Other remote technology research includes mobile teleoperator/robotics technology for the U.S. Army Human Engineering Laboratory (HEL). Under the auspices of HEL, RISP personnel are also contributing to the Technology-Based Enhanced Autonomous Machines (TEAM) program, which involves using multiple cooperating agents on the battlefield.

RISP personnel are responsible for remote handling and manipulation of the three U.S. fusion initiatives: Tokamak Fusion Test Reactor (TFTR), which is operating; Compact Ignition Tokamak (CIT), which is under development; and the International Thermonuclear Experimental Reactor (ITER), which is a planned cooperative effort among the United States, the Soviet Union, the European Community, and Japan. In research programs funded by NASA, RISP has designed, built, and delivered the Laboratory Telerobotic Manipulator (LTM) system, which combines the best attributes of force-reflecting servomanipulators and classical positioning robots to provide a reconfigurable, modularized, telerobot manipulator. The U.S. Air Force Wright Research and Development Center supports research in multisensor integrations and real-time decision making for SDI applications.

Under the auspices of HEL, RISP personnel have begun testing and modifying the Army's new HMMWV (jeep) for effective remote operation. A feasibility study for the Strategic Defense Initiative Organization (SDIO) on maintenance of space-based reactors was initiated. A new initiative has been authorized for the Army's Fort Belvoir Laboratory, which uses the HERMIES-III vehicle for studies in combined mobility/manipulation. In addition, Belvoir has requested RISP support in hardware evaluation and development. Another new activity has begun in support of the Army's Harry Diamond Laboratories involving development of a high-performance VME system.

A program involving automation of ammunition logistics as part of the Army's Future Armament Resupply System has been initiated, leading to a simulated demonstration in late FY 1991. NASA-Lewis has initiated support of the development of a four-degree-of-freedom microgravity manipulator based on LTM technology.

Finally, a major new activity concerns development of robotics for decontamination and decommissioning of enrichment facilities; this potentially large RISP effort is now in the proposal stage.

RISP builds upon ORNL's strengths in teleoperations and intelligent 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.

Applied Technology Division

The Applied Technology Division (ATD) became part of ORNL in 1988. The division was created in FY 1985 using the facilities and personnel that had been involved on gas and liquid centrifuge R&D. The division now applies the technology developed in 25 years of centrifuge R&D to DOE and other federal agency programs and national competitive initiatives (Table 33).

ATD is well positioned to support DOE energy-related missions because of its many assets and its experience in R&D, design, manufacturing development, and prototype fabrication and evaluation. The assets include a full range of capabilities in

- advanced polymeric composite materials (Fig. 46);
- manufacturing R&D and precision prototype fabrication and assembly capabilities;
- remote measurements, electro-optics, and sensor R&D;
- state-of-the art data acquisition, data transmission, and signal analysis;
- extensive experience in complex electromechanical systems design, operation, and evaluation; and
- a full range of analytical and design capabilities in high-speed machinery including elastic/inelastic stress, creep, very high mach number supersonic flow/inlet design, thermodynamics, acoustics, and magnetic bearing technology.

ATD capabilities in advanced polymeric composite materials and structures, machinery, electro-optics, systems engineering, and isotopes represent areas of expertise that are both unique and synergistic with other resources located at ORNL. Capabilities in areas such as organic matrix composite materials and lightweight, high-energy-density motors and generators represent areas of national and international technology leadership. Currently, ATD has over 40 sponsors from DOE, DOD, and the private sector.

Examples of current advanced technology applications include (1) a prototype pressure hull for the Navy autonomous search and surveillance minisubmarine that is considered to be the state-of-the-art in the application of advanced materials to Navy submersible structures; (2) the development of a compact data-acquisition system and state-of-the-art sensors for use by the U.S. Navy to develop advanced torpedo technology; (3) the development of a phosphor-based temperature-measurement system for the U.S. Air Force for application in the development of advanced turbine engines; (4) a laser-based automated thermoplastic consolidation for manufacturing thick panels with variable geometry for private industry and the Air Force; (5) the development of an innovative, compact, high-power-density superconducting motor for EPRI and DOE, which has significant potential for

Table 33. Applied Technology Division[a]
($ in millions)

	1988	1989	1990	1991
DOE (CD)	5.9	9.5	7.4	5.7
Other DOE/Martin Marietta Energy Systems, Inc.	3.0	3.1	3.6	4.4
DOD	10.7	12.3	15.5	17.4
NASA	0.2	0.2	0.2	0.2
Private, State, Local	0.9	1.5	1.6	1.8
Total	20.7	26.6	28.3	29.5

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

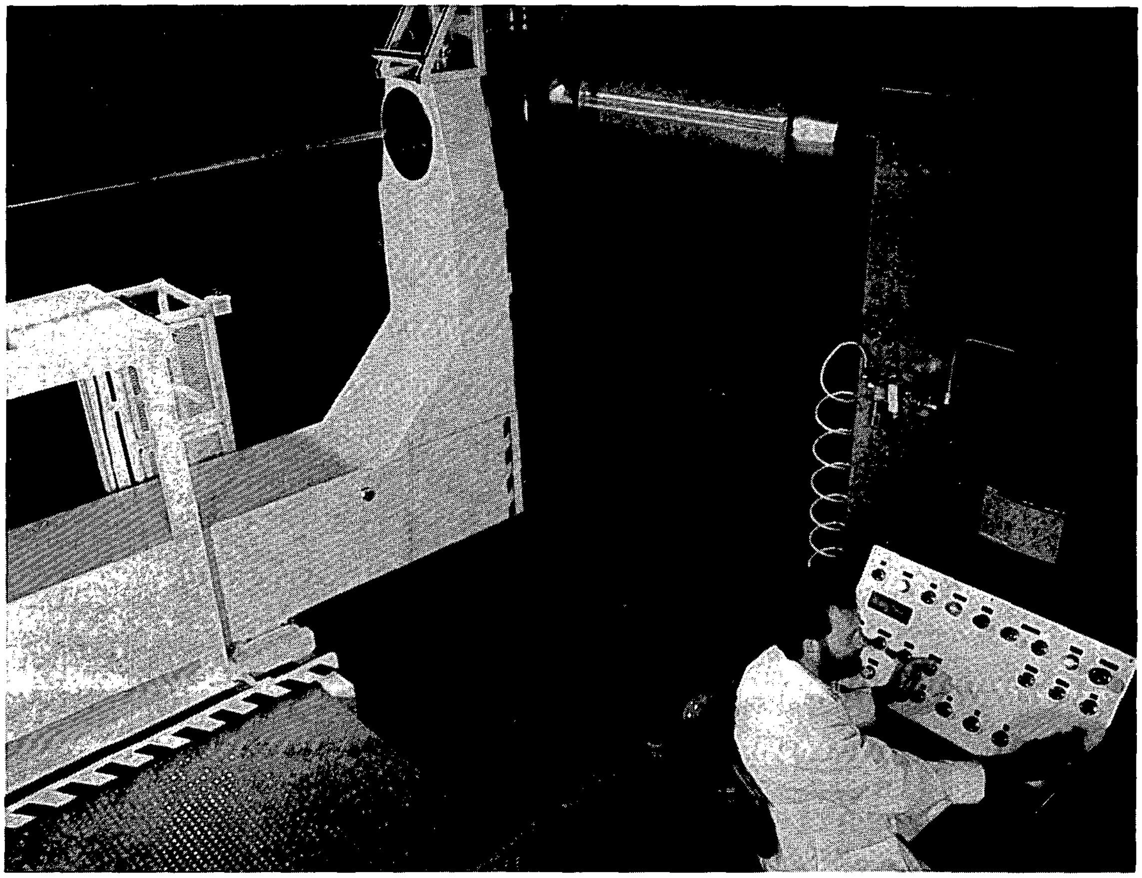


Fig. 46. Sophisticated machinery is used to wind fibers onto mandrels, producing either fiberglass- or graphite-based composite structures.

defense and commercial applications; and (6) application of composites technology to the Compact Ignition Tokamak.

In 1986 while discussing polymeric composite materials applications with industry and other government agencies, ATD discovered a severe lack of data, coordination, and communication relative to the science and engineering application of thick polymeric composites in compression. Because this situation poses a major impediment relative to the use of these materials in any complex structure, a workshop on Thick Composites in Compression was held in 1986. The 1986 workshop, sponsored solely by ORNL, attracted 24 participants from ORNL, universities, and the Air Force and Navy. The 1989 Workshop, which is sponsored by the Society for Advancement of Material and Process Engineering (SAMPE), the Defense Advanced Research Projects Agency (DARPA), the Office of Naval Technology, the U.S. Army, the Wright Research and Development Center (WRDC), and ORNL, attracted 240 participants from universities, industry, DOE, and DOD.

ATD also holds the Thermoplastics for Space Workshop sponsored by WRDC. The objective of this workshop is to provide transfer of technology between spacecraft design engineers and advanced structural materials suppliers, fabricators, and users. The first workshop held in 1986 attracted 40 participants while the 1989 workshop attracted approximately 100 participants from DOE, DOD, and industry from the United States and the United Kingdom. As a result of the successful Thick Composites and Thermoplastics workshops, the U.S. Air Force asked ATD to put together the

Advanced Structural Materials (ASM) workshop in support of the Strategic Defense initiative (SDI) program. The ASM workshop, which was held September 1989 in San Francisco, focused on thermoplastics, thermosets, carbon-carbon, metal matrix, and structural damping.

The initiation of these workshops by ATD has helped ORNL facilitate the transfer of technology to the private sector and is enhancing the reputation of ORNL as a national materials technology resource. The current programmatic initiatives within ATD also include the following:

- an organic matrix composites initiative with The University of Tennessee,
- the application of system-engineering modeling and 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 application of unique electro-optic measurements and data-recovery systems for noncontact and nonintrusive measurements in hazardous environments over temperatures ranging from cryogenic temperatures to 1000°C, and
- the cleaning of facilities formally used by the gas centrifuge program in order to make these facilities available for an expanded program by ATD and other ORNL divisions.

Waste Management Technology Center

The Waste Management Technology Center (WMTC) ensures that the latest technology applicable to waste treatment and disposal problems at Martin Marietta Energy Systems, Inc. (Energy Systems), is recognized; understood; and when necessary, demonstrated. The WMTC also develops and demonstrates waste treatment technology funded through the ORNL Hazardous Waste Technology Program (HWTP). These include projects funded by DOE's Hazardous Waste Remedial Action Program (HAZWRAP) (GF funding) and hazardous waste technology R&D projects that require the technical strengths of a multidisciplinary team drawn from various divisions within Energy Systems. For instance, HWTP is currently managing remediation technology R&D projects for the Air Force and Navy.

The WMTC also facilitates technology transfer by conducting workshops on waste management topics of primary interest to the DOE-ORO sites. In FY 1988, WMTC conducted the first of a series of workshops on the following subjects: leaching tests, uranium-bearing wastes, contaminated soils, and RCRA/CERCLA issues. The workshops are expected to continue and to cover other waste management topics of interest to the sites. The workshop on uranium-bearing wastes led to funding for a Uranium Task Force to address this problem on a DOE-wide basis. The Uranium Task Force is funded by the National Low-Level Waste Program, another program whose ORNL tasks are managed by WMTC.

The WMTC works extensively with HBCU coordinators for Energy Systems and DOE-ORO in supporting HBCUs in developing waste treatment R&D projects that can be conducted at their institutions.

Scientific and Technical Information Centers and Data Bases at ORNL

The Oak Ridge National Laboratory 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 Work for Others (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 a 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 The 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 is comprised of 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.

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 Remedial Action Programs, which include Surplus Facilities Management Program (SFMP), Formerly Utilized Sites Remedial Action Program (FUSRAP), and Uranium Mill Tailings Remedial Action Program (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 (NIEHS), and the Agency for Toxic Solutions and Disease Registry (ATSDR); 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 complied 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. CURE is available to users through hard-wired direct entry, or direct commercial telephone entry. 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.

Hazardous Substances Data Bank The Hazardous Substances Data Bank (HSDB) is a numeric, factual, nonbibliographic data base focusing on the toxicology of potentially toxic/hazardous chemicals. It is enhanced with data from such related areas as emergency handling procedures, environmental fate, human exposure, detection methods, and regulatory requirements. Data are derived from a core set of standard texts and monographs, government documents, technical reports and the primary journal literature. Complete references for all data sources are included. HSDB is fully peer reviewed by the Scientific Review Panel (SRP), a committee of experts drawn from the major subject disciplines within the data bank's scope.

Since 1974, the HSDB file has been built, maintained, reviewed, and updated on the National Library of Medicine (NLM) Toxicology Data Network (TOXNET) in collaboration with ORNL. HSDB contains approximately 4200 chemical substance records. HSDB is sponsored by the National Library of Medicine and ATSDR.

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. Information is organized by chemical compound and includes records on approximately 2400 generic chemicals and an additional 3600 trade name products. The MSDS File is used by Martin Marietta Energy Systems facilities and other DOE national laboratories. The MSDS File is sponsored by Energy Systems and the DOE Toxic Materials Advisory Committee.

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.

Work for Others

In addition to DOE-funded programs, ORNL undertakes R&D programs for other federal agencies and other organizations. Work-for-Others (WFO) is conducted in areas that are consistent with and complement ORNL's DOE missions. Major federal agency sponsors include the Nuclear Regulatory Commission (NRC), the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), the Department of Health and Human Services (DHHS), the Environmental Protection Agency (EPA), and others. ORNL's nonfederal projects include work for the Electric Power Research Institute (EPRI), the National Association of Home Builders, and the American Petroleum Institute (Table 34).

Federal Organizations

Current ORNL efforts for the Nuclear Regulatory Commission reflect the changing priorities of the commission, public attitudes toward the safety of nuclear power, and the maturing of the U.S. nuclear industry. The slowdown in construction of nuclear plants, combined with the upcoming expiration of the licenses of currently operating power plants, has shifted research emphasis toward structural and component safety issues, reactor operational data analysis, advanced instrumentation and diagnostics, and plant-life extension. Based on current NRC budget projections, ORNL efforts are expected to increase slightly in FY 1990 and remain reasonably stable thereafter.

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,

Table 34. Work for Others program resource summary
[$ in millions—budget authorization (BA)]

	1988	1989	1990	1991
Federal organizations				
Nuclear Regulatory Commission	12.8	15.8	16.1	16.3
Department of Defense	40.2	44.8	55.5	56.3
National Aeronautics and Space Administration	2.9	2.4	2.5	2.5
Department of Health and Human Services	4.9	4.6	5.5	6.0
Environmental Protection Agency	4.2	4.3	4.5	4.5
National Science Foundation	0.9	0.5	0.9	1.1
Federal Emergency Management Agency	1.7	1.3	2.3	2.3
Agency for International Development	2.1	0.9	1.7	1.7
Department of the Treasury	14.5	0	0	9.0
Other federal agencies	1.8	1.5	1.6	1.6
Nonfederal organizations				
Electric Power Research Institute	5.7	3.6	2.0	2.0
Other nonfederal organizations	2.8	2.3	2.2	2.1
Total	94.2	82.0	94.8	105.4

the major sponsor of ORNL activities, initiates comprehensive research programs and standards development for the Commission. NRR is charged with implementing regulations dealing with licensing and inspection of the commercial nuclear industry. These regulations are based on knowledge obtained from the research programs. AEOD 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 in the areas of long-term behavior of reactor pressure vessels and in extension of the operational life of existing power plants beyond their original design, including research into the aging characteristics of plant components, will increase somewhat over the planning period. Efforts in the area of behavior of fission products in severe accidents (Fig. 47) are expected to decline as various issues are resolved. Research into artificial intelligence, human factors, and modular high-temperature, gas-cooled reactors is anticipated to increase over the planning period. During FY 1989 the single largest program supported by RES, the Heavy-Section Steel Technology Program, has been reorganized into two distinct programs: Heavy-Section Steel Technology, emphasizing fracture mechanics activities (Fig. 48), and Heavy-Section Steel Irradiations, emphasizing irradiation effects on structural components. The increased regulatory concerns in the area of embrittlement prompted the reorganization. The Laboratory's expertise in the area of materials embrittlement continues to provide NRC with much of the available data in this field.

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 was begun during FY 1989. A slight increase in funding is expected for FY 1990.

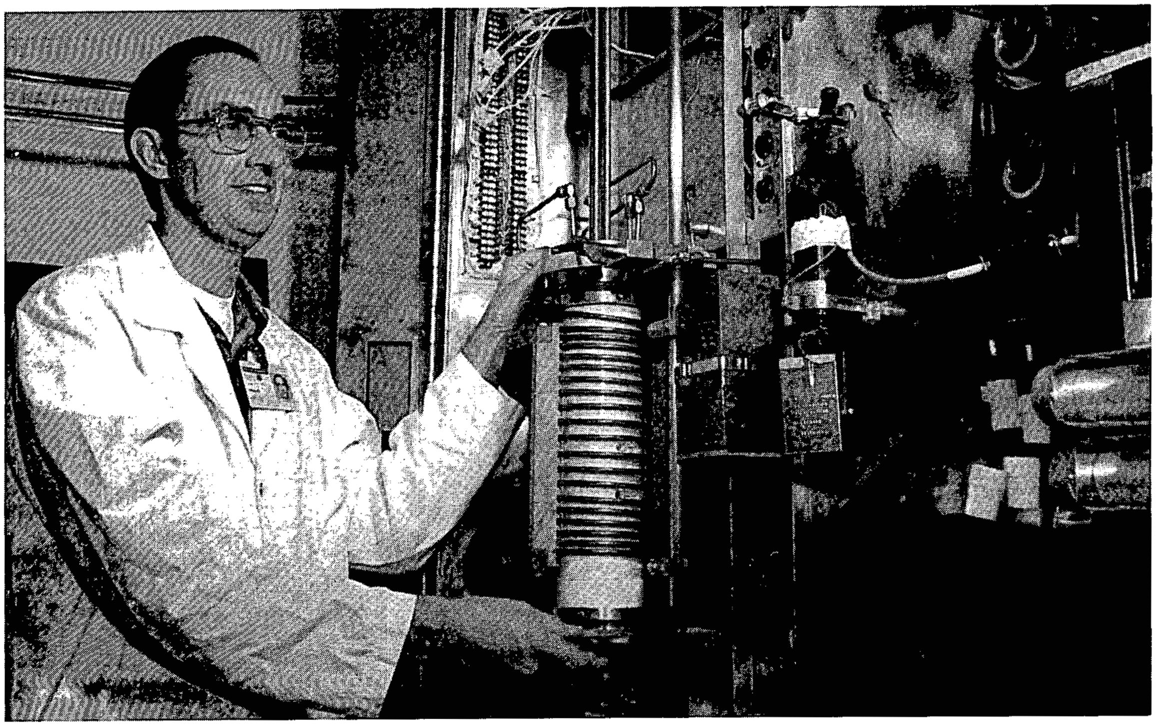


Fig. 47. Fission product release apparatus used here by Jim Travis to obtain data applicable to the analysis of reactor accidents.

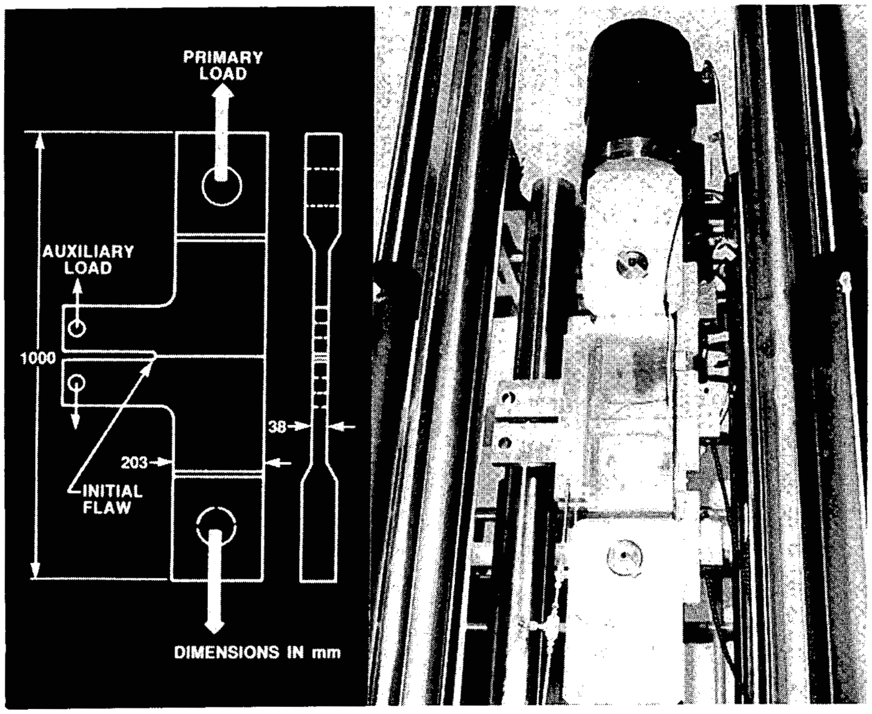


Fig. 48. Stub-panel tests provide crack-arrest data for use in integrity assessments of reactor pressure vessels under potential pressurized thermal shock scenarios (sponsored by the U.S. Nuclear Regulatory Commission).

Nuclear Reactor Regulation Using expertise developed in RES programs, ORNL provides technical consultation and assistance to NRR. On-call assistance is currently being provided in the interpretation of nondestructive evaluation data, in analyses of fuel stability, in the review of licensing documentation, and in failure modes and effects analysis. A significant effort also involves the thermal-hydraulic stability of BWR cores or fuel assemblies. Funding is expected to remain relatively stable over the planning period.

Nuclear Material Safety and Safeguards The Office of Nuclear Material Safety and Safeguards sponsors shipping-cask analyses, environmental assessments of fuel cycle facilities, technical support and laboratory-oriented evaluation in geochemical areas related to the licensing of radioactive waste repositories, and a survey of metabolic data appropriate to high-level waste (HLW) dosimetry. Because of the establishment of a federally funded R&D center, HLW work has been curtailed. A new initiative in the area of licensing of uranium enrichment facilities was begun in late FY 1989 and will continue into FY 1990. 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 procedures changes.

Department of Defense

Space and Defense Technology ORNL technology has made a substantial contribution to many DOD programs and could take an expanded role in the next 3 to 5 years as state-of-the-art technologies are required to meet new complex and challenging military program requirements. To help meet this challenge, a significant internal reorganization occurred in April 1988 to strengthen our work for DOD through the formation of a coordinated program area for Space and Defense Technology (SDT). This reorganization consolidated the work previously conducted under the Strategic Defense Initiative (SDI), Defense Technology (DTP), and the Acoustic Instrumentation R&D (AIRD) programs. The mission of the SDT program is to capitalize on the unique R&D capabilities located at each plant site in Oak Ridge and to further develop and transfer these technologies to important military applications.

ORNL performs R&D for the major DOD services (U.S. Army, Navy/Marines, and Air Force), as well as joint agencies such as the Strategic Defense Initiative Office (SDIO), Defense Advanced Research Project Agency (DARPA), Defense Nuclear Agency, and several other defense-related agencies. Work for the major DOD services and some of the more significant joint agency efforts are discussed below. Although the SDT program involves work at all three Oak Ridge facilities (i.e., Y-12 Plant, ORGDP, and ORNL), only the ORNL funding and personnel are shown in this document.

Army ORNL research for the Army includes programs in materials science and technology, instrumentation and control systems, robotics, transportation systems, operations research, and environmental analysis and assessment. Work for the Army is expected to expand moderately.

A major new initiative in materials research was started to understand and better predict the aging of materials used in Army munition stockpiles for the Army Research, Development and Engineering Center. Advanced materials R&D in composites, ceramics, carbon/carbon, intermetallics, and related technologies for the development of advanced armor and shielding or lighter-weight components for increased mobility of weapon systems and vehicles are also expected to increase for the Army Materiel Command, U.S. Army Laboratory Command, and related agencies. Work is expected to expand on advanced materials for reentry vehicles and space applications for the Space Development Command.

Several new initiatives were begun in advanced instrumentation and robotics technology, including advanced robotics concepts for the Army

Laboratory Command and related prototype applications for the Army Troop Support and Chemical Commands. New programs in laser and communications technology for battlefield environments are also planned.

ORNL continues to support major environmental assessments, including (1) assessment for the safe disposal of obsolete chemical weapons stockpiles, (2) the development of emergency response plans, and (3) the Installation Restoration Program. Environmental analysis to assess the potential impact of changing military operations at specific sites or broader programmatic missions is expected to expand. This work will include developing new environmental measurement and analytic techniques for laboratory and field applications. Work is also expanding in analytical chemistry to characterize chemicals (such as military fuels) and their by-products.

R&D for the Army in operations research and transportation systems, energy conservation and energy security and fuels research, and related advanced engineering will expand. Research to develop new systems to modernize emergency planning, transportation, recruiting, and force structure, and related systems for the National Guard Bureau is planned to grow rapidly for the next 3 years.

Navy and Marine Corps ORNL conducts research for the Navy and Marine Corps on engineering systems, instrumentation, data systems, reliability and maintenance, materials R&D, fuel supply and use, diesel testing, energy conservation, and waste disposal. Work for the Navy and Marine Corps will increase in FY 1990 and succeeding years.

ORNL continues an important role in instrumentation and engineering R&D for the David W. Taylor Research Center (DTRC). The DTRC is the U.S. Navy's principal research, development, test, and evaluation center for naval vehicles. Two primary areas of interest to DTRC are (1) ship and submarine silencing and (2) methods to design and test high-strength hulls and components. A principal R&D method for DTRC is the use of experimental models of proposed submarine designs, including models of components and of complete submarines. Most models are built to large scale and are highly instrumented, with on-board computer-based data-acquisition systems and other instrumentation. ORNL provides assistance to DTRC in the design and development of R&D instrumentation systems for these and other test facilities used in the development of new ship and submarine designs and for the support of the current fleet.

In addition to the DTRC work, a potentially major new activity was begun late in FY 1988 to evaluate new technologies for the Navy's advanced submarine R&D program. The work is planned to support the new emphasis in DARPA and the Navy.

Increased R&D is expected on instrumentation and equipment reliability and maintenance and new techniques to modernize naval systems, especially in the areas of logistics, mobilization planning and modeling, command and control, marine telecommunications, environmental technology, and computer-aided instruction.

ORNL research for the Navy in transportation logistics and fuels, diesel testing, energetic materials, and ordnance systems is expected to continue at about the same level.

Air Force For the Air Force, ORNL conducts research on environmental systems, advanced materials R&D, advanced fuels research, data systems, waste management, and many other related activities. Work for the Air Force is expected to expand moderately.

The Applied Technology Division (ATD) is currently working with the Air Force Wright Research and Development Center (WRDC) on the development and evaluation of thermoplastic composite materials for space applications, the development of design/analysis and fabrication techniques for thick composites, the design and test of a laser-based thermoplastic consolidation system, and the design and evaluation of foil-lined composites for cryogenic 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 is currently supporting the Military Airlift Command in the development of the Airlift Deployment Analysis System, which involves traffic routing, artificial intelligence, and operations research to assist in both peace and wartime situations. This activity is projected to increase.

Advanced materials work for the Air Force includes the study of lightweight structures. Structures are being evaluated which use the extensive expertise developed in the weapons and centrifuge programs for the fabrication and testing of structures made of high-temperature carbon/carbon composites and other high-strength materials.

Strategic Defense Initiative The SDI program in Energy Systems uses the special capabilities of all three Oak Ridge facilities (i.e., Y-12 Plant, ORGDP, and ORNL). 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 next year will be heavily influenced by the national SDI policy set by the Bush administration.

Several significant program changes are expected in the next few years. The SDI Survivable Optics Manufacturing Operations Development & Integration Laboratory (MODIL) program and the Radioisotopic Thermoelectric Generator/Dynamic Isotope Power System program are expected to expand significantly over the next 2 years. The SP-100 program has expanded at ORNL to include some sensor and radiation-shielding development and is planned to increase moderately in FY 1990.

The MODIL program is a major new SDI initiative that was begun in FY 1988 and continued at an expanded pace in FY 1989. This program will 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 mirror 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, recently, 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.

Data Systems Research and Development The mission of the Data Systems Research and Development (DSRD) program is to create and maintain a center of excellence for the research and engineering development of advanced data systems and information security technologies. Through program management, research, development of one-of-a-kind 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, design of an aircraft scheduling and deployment algorithm for the Military Airlift Command, and design of Navy financial systems using artificial intelligence design and control programs. 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; and parallel computing R&D for the Joint Worldwide Military Command and Control Information Systems Program Office. DSRD is also sponsoring Dr. Jose-Marie Griffiths, information scientist, in her collaborative scientist (joint) appointment with UTK and Martin Marietta Energy Systems, Inc.

Hazardous Waste Research and Development The varied and complex waste issue at Oak Ridge covering 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.

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. DSRD is also active in site characterizations for various federal sponsors.

Technology development is currently provided to the Air Force Engineering Services Center, NEESA, and the 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.

National Aeronautics and Space Administration

As described under the Other ORNL Programs section, NASA provides funding for ORNL's Robotics and Intelligent Systems Program, including the design and construction of the Laboratory Telerobotic Manipulator system. NASA support is expected to remain stable or grow during the next 5 years (Fig. 49).

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, which include the following:

- 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 General Medical Sciences;
- National Institute of Child Health and Human Development;


Fig. 49. NASA access experimental space truss being assembled by the ORNL M-2 servomanipulator. The feasibility of assembling typical space hardware with remote manipulation was examined in this test.

- 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.

ORNL is also to continue providing technical expertise to NLM in building and maintaining the Hazardous Substances Data Bank (HSDB). As mandated by SARA, HSDB provides comprehensive peer-reviewed chemical information profile for 4200 toxic/hazardous substances. These are commonly found at the hazardous waste sites and exposed to human population. NLM is also supporting research on the development of a portable computer-based emergency response system.

The Food and Drug Administration's National Center for Toxicological Research (NCTR) is funding the development of a fully integrated automated-research-support system. This system will be a state-of-the-art laboratory management system that will be useful to other animal-breeding and toxicology laboratories. The project is starting with the development of one of the major modules, the Breeding/Multigeneration Support System.

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-β 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 carcinogenesis induced by environmental agents is being tested. A mouse-model system is being used to investigate whether the mouse chromosomal LTR-containing retroviral gene elements are capable of initiating genetic transposition following 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

Overall, our EPA program will continue at about the FY 1990 level of effort with fluctuations in specific program areas. Our work for EPA addresses numerous health, environmental, and economic problems and issues, particularly research in the toxic effects of pollutants associated with energy-production processes and waste disposal. Health and environmental risk analysis and epidemiological studies continue to be important components of this work. We are involved in the development of biomarkers for assessing exposure and effects of environmental contaminants.

Recently ORNL began work to evaluate the economic viability of recycling solid waste, with emphasis placed on plastics recycling. In addition, work is under way to evaluate 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.

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 profiles for oral and inhalation exposures,
- Tier-I health effects assessment documents, and
- risk assessment methodology development—reduce uncertainty in risk assessment.

Data-base development activities for EPA are expected to increase. An evaluated data base, chemical unit risk estimate (CURE), is under development for the Office of Health and Environmental Assessment. 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.

Acidic deposition research activities will decline in FY 1990. Major emphasis is on the effects of acidic precipitation on forest and aquatic systems and on ion mobility in soils, with integrated assessment support to the National Acid Precipitation Assessment Program. Other FY 1990 research will focus on development and application of models for evaluating the regional effects of changes in acid-base chemistry on fisheries. The Laboratory's role in data analysis for the national survey of streams will end in FY 1990, as will support for the Direct/Delayed Response Program. In FY 1990 ORNL is expected to support program planning, development, and implementation of two new EPA initiatives in

Long-Term Environmental Monitoring and Assessment and in Global Ecological Effects.

New research in advanced data systems has begun for EPA's Office of Planning, Budget, and Program Management to develop computer-analysis capabilities that will allow EPA to better formulate environmental regulatory policy and to analyze groundwater-contamination problems. Environmental risk analyses will continue with emphasis on assessing risks to marine biota. At the Laboratory, emphasis focuses on using ecosystem models to assess the risks of chemical releases to aquatic environments and to identify the ecological requirements of estuarine species. In addition, ORNL is participating in the development of EPA's new climate change initiative and will 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 options for the Office of the Administrator.

National Science Foundation

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. The National Science Foundation (NSF) recognizes ORNL's leadership in ecosystem research 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.

With NSF (and EPA) support, ORNL researchers are developing biologically based pharmacokinetic and pharmacodynamic models for predicting chemical transport and metabolism across routes of administration, across species, and through temporal variations in time and for relating genetic mutation frequencies and cell turnover dynamics to the epidemiology of cancer in animal and human populations.

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 for over 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 emphasizes radiation detection and protection and includes developing low-cost dosimeters and rate meters and assisting in hardening civil defense installations against electromagnetic pulse effect.

Analysis and assessment activities include building economic models of preparedness options, assisting with the use of computer graphics, and working on shelter concepts for emergency protection. These activities will also include the following issues:

- emergency response to chemical accidents,
- postdisaster economic recovery,
- restoration of electric power,
- restoration of water and sewage systems,
- expedient supplies of energy and other critical commodities,

- industrial mobilization,
- data sources for emergency management, and
- Civil Defense program planning.

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 Agency for International Development (AID) on technical aspects of energy planning and energy technology applications for developing countries. 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,
- power system development,
- renewable energy technologies, and
- fossil energy technologies.

Department of the Treasury

Intradivisional ORNL projects involving manufacturing automation, quality assurance, and counterfeit deterrence have been sponsored by the Bureau of Engraving and Printing, a branch of the U.S. Department of Treasury, since 1984. 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. Three 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 Currency Finishing System, will print and inspect currency seals and serial numbers, then cut the rolls into notes, and package the notes that passed machine inspection. A third prototype, the Web Stamp Inspection System, uses specialized sensors to inspect special features of postage stamps at web speeds up to 1800 ft/min. Research associated with the engineering prototype development includes human-vision analysis, ink chemistry, color measurements, high-speed image analysis, alternate printing methods, and manufacturing systems analysis.

Department of Transportation

Transportation Research at ORNL covers all modes, with particular attention to highway transportation that accounts for over 73% of the nation's energy used on travel. Currently, ORNL is assisting the Federal Highway Administration (FHWA) on research into vehicle-miles-of-travel (VMT) forecasting for both automobile and truck traffic.

FHWA is concerned about data quality and data consistency because highway programs and policies can not be evaluated and planned effectively without consistent information. Technical assistance is being provided by ORNL to evaluate various data sources in terms of their ability to estimate the number of heavy commercial trucks operating in interstate commerce and the vehicle miles traveled by these trucks. Based on this evaluation, ORNL is to recommend the best estimation method.

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.

Innovative log-linear modeling of VMT 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 VMT 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. Application of expert-system methodologies to traffic simulation problems is emerging as a future research area.

Department of the Interior, Bureau of Mines

ORNL is developing some innovative resource-modeling techniques for the DOI's Bureau of Mines that will be used to study the relative competitiveness of the U.S. minerals industry, the impacts of acid rain legislation on the minerals industry, and the economic impacts of the development of advanced materials.

Other Federal Agencies

ORNL also provides technical support to a variety of other federal agencies, including the Consumer Product Safety Commission and the National Oceanic and Atmospheric Administration. We anticipate collaborative work with the U.S. Department of Agriculture (USDA) Forest Service in environmental research. Some support has been provided by the U.S. Department of State for work performed for the International Atomic Energy Agency and UNESCO. Collaborative research for the Park Service is taking place at the Great Smoky Mountains National Park. ORNL is helping the Department of Commerce, Bureau of the Census, plan the year 2000 census by assisting in managing changes in technology. Support has also been provided by the U.S. Department of Education, U.S. Department of Justice, U.S. Department of Labor, and TVA.

Nonfederal Organizations

Electric Power Research Institute

Research sponsored by EPRI addresses critical national issues related to electric power generation. 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,
- evaluating the role of compensatory mechanisms in fish populations, and
- developing a mechanistic and predictive forest-cycling model to address potential future impacts of atmospheric deposition.

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 Mechanism Project. In FY 1990 the Compensation Mechanism Project may be 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 carbon dioxide (CO_2) and global climate change.

EPRI continues to fund research at ORNL in areas related to the efficient use of electric energy. Efficiency research projects sponsored by EPRI that are currently under way include testing of full-size ice-storage systems for cooling commercial buildings and testing radiant-barrier systems in residential attics. DOE and EPRI share a wide range of common interests in research in electric power systems technology, least-cost utility planning, and end-use efficiency. It is expected that EPRI will continue to cofund and participate in projects in these areas.

National Association of Home Builders' Smart House Project

ORNL is a participant in the Smart House Project, a cooperative effort between the National Association of Home Builders and a number of manufacturers of home-construction products. ORNL is providing technical evaluations of proposed Smart House Designs and advising project participants on methods suitable for design evaluation and system integration. The project will help the participants incorporate advanced technology in new products for communications, energy distribution, and appliance control. ORNL is currently developing prototype test equipment for validating the system concept. (Funding is estimated at ~\$200,000 for FY 1989–1992).

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.

Other Nonfederal Organizations

ORNL performs work for several nonfederal organizations:

- 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;
- Adirondack Lake Survey Corporation;
- Metropolitan Edison/General Public Utility;
- Pacific Power and Light;
- EG&G Energy Measurements, Inc.;
- Florida Institute of Phosphate Research;
- Gulf Oil;
- Battelle Laboratories;
- General Electric;
- American Petroleum Institute;
- National Association of Home Builders Research Foundation;
- Soap and Detergent Association; and
- National Geographic Society.

Education and Technology Transfer Programs

University and Educational Programs

Overview of ORNL's University and Educational Programs

The DOE University Laboratory Cooperative Program (ULCP), Office of Energy Research (ER), supports research participation and training for students and faculty at ORNL through both ORNL and 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. About 1400 university-based researchers are hosted annually at ORNL; fewer than 300 are supported by ULCP. In addition, many ORNL divisions have long-standing collaborative research projects with internationally renowned university faculty.

ORNL plays an important role in the education and training of university students through a myriad of programs designed to provide research experience (Table 35). Over 1400 annual guests at ORNL are affiliated with universities, either as precollege students, undergraduate and graduate students, faculty, or postgraduate appointees. Most of these guests visit for short-term research projects, but about one-third are assigned full time to ORNL divisions for research that may last from 1 to 2 years, producing about 450 person-years of program assistance. They are hosted by the Laboratory through a variety of mechanisms:

- awarding R&D 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 lending personnel and equipment resources, and
- establishing close collaborations with specific universities and university consortia.

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 fields such as 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 ORNL's Office of University and Educational Programs whereby students and faculty participate in research at the Laboratory. These arrangements are attractive to the Laboratory because they usually cost less than it would to hire additional staff and still maintain quality work.

In addition to being cost effective, university personnel make substantial contributions to ORNL's missions. For example, important contributions were made by a former postdoctoral appointee and current postdoctoral appointees in the design, construction, and operation of the scanning-tunneling microscope in the Health and Safety Research Division. Over the two decades that ORNL has hosted undergraduate students on academic-year science semester programs, students

Table 35. **Programs at Oak Ridge National Laboratory for Precollege and University Participants (FY 1989)**

Precollege	
Special honors study	4
Honors workshop	51
Project SEED	8
Ecological and Physical Sciences	10,000
Study Center	10,000
Total	10,063
Undergraduate	
GLCA/ACM science semester	25
Summer research internship	42
Net Historically Black Colleges and Universities (HBCU)	11
Technology Internship Program	15
Special Summer Program	8
Science and engineering research semester	36
Student research participation	54
Summer forestry	2
Total	193
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	16
Office of Health and Environmental Research (OHER) postgraduate appointment	2
Postgraduate research training	25
Hollaender Postdoctoral Program	4
Total	47
Faculty	
Faculty research participation	34
Research travel contract	152
MIRT	5
OHER HBCU faculty	3
Nuclear Regulatory Commission (NRC) HBCU faculty	3
VISITS Program	15
TRA	13
STAR	4
Science Teachers' Research for Vital Involvement (STRIVE)	11
Total	240

have made substantive contributions to ORNL projects that later were patented and/or received R&D 100 Awards. Furthermore, working with university personnel fulfills, in part, the Laboratory's technology transfer objectives.

Over 30 different programs provide opportunities for students and faculty to participate in research at ORNL for appointment periods ranging from 2 weeks to several years. About half 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 ULCP and programmatic funds.

About 130 co-op students were employed by ORNL in FY 1989. An additional 200 students, 45 postgraduates, and 35 faculty received research-participation appointments through programs managed by the Laboratory's Office of University and Educational Programs. These appointments exclude the almost 150 who received research 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 (VISITS). 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 that 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 with ORAU and SURA in a new initiative to establish a Center for Advanced Study in Materials Science at ORNL. 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 Ph.D degree. Papers will be issued through ORNL for the participants to receive their degrees. ORNL also continues a strong semester program with the Great Lakes Colleges Association/Associated Colleges of the Midwest (GLCA/ACM), which is now in its second decade.

Research and Development Subcontracts

ORNL awards about 250 R&D subcontracts to over 100 universities annually. These subcontracts generally sponsor research on campus, but they may also include provisions for student internships or faculty appointments to perform research at the Laboratory. About 35% of ORNL's subcontract obligations are with The University of Tennessee, Knoxville (UTK) (including the cost for the joint appointments under the Distinguished Scientist Program).

In FY 1988, universities in a majority of states, Puerto Rico, and Canada received research funding from ORNL. Program HA (now KP) was the largest sponsor of university subcontracts, accounting for about 18% in FY 1988. Other major sponsors of university research were Program EB (16%), Program EE (13%), and Program AA (10%). A large percentage (over 45%) of the university subcontracts were sponsored by Work-for-Others agencies.

Research Collaborations

Many long-standing, close collaborations exist between ORNL and individual universities that are based on mutual research interests. 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 and/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. This 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.

In FY 1989, ORNL 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. Social science activities will be expanded to address human cause-and-effect relationships and to analyze policy options for mitigation strategies. 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 the equipment 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 personnel and resources. ORNL staff members frequently give seminars at universities throughout the nation, either because of 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 25 to 30 adjunct professors from ORNL receive compensation under official appointments from The University of Tennessee. 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's manpower training programs sponsored by DOE. ORNL also provides other types of assistance to faculty, including critical review of proposals and manuscripts and organizing joint meetings and conferences.

Facilities and Equipment at ORNL

ORNL is the home of 13 official 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 1988, nearly 300 university researchers performed experiments for 4000 user days in ORNL's DOE user facilities. The largest percentage of the university-based users (33%) perform 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 (SMAC/CRC).

Other unique resources that may be available to university researchers include supercomputing capability (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. The quantity and quality of science and mathematics training at both the college and precollege levels are declining. Some of the problems have been manifested in the university in terms of poor precollege preparation and declining enrollment, especially of U.S. citizens and 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. University and Educational Programs works 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 so that attendees can learn of the variety of research that takes place at ORNL.

For several years programs have existed to make the Laboratory available to high school students and teachers. Beginning in the summer of 1985, 14 high school teachers were participants in the pilot Summer Field Experience program that allowed them to assist ORNL researchers for 6 weeks.

Two new summer research programs, the Teacher Research Participation (TRA) and the Summer Teachers as Resources (STAR) programs, were established during FY 1989. The TRA program, sponsored and funded by DOE-ER, 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. The goal of STAR, a pilot program, 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 1989, 22 teachers participated in research activities at ORNL under the management of University and Educational Programs. A teachers' advisory group, Partners for Resources in Science and Mathematics (PRISM), has been working with area teachers in providing workshops and equipment loan programs. The workshops seek to link the "big science" of the Laboratory with the existing science curriculums. The equipment loan program attempts to provide teachers with needed equipment. Another teacher-oriented initiative in FY 1989, PRISM Associate Teachers, encourages teachers to link with Laboratory personnel to enhance their own knowledge in a given area and to develop materials appropriate for their teaching assignment. For example, one teacher has worked with staff in ORNL's Solid State Division to develop materials linking superconductivity to traditional science topics. This material was consequently used as part of official DOE materials recognizing National Science and Technology Week, and it was used as a component for a National Science Foundation (NSF) teacher enhancement proposal. Another teacher is developing curriculum materials in the area of genetics, working through a mentorship in the Biology Division.

Programs established for high school students have been expanded, and new programs have been implemented. ORNL hosted the DOE National High School Honors Workshop in FY 1989 in the environmental sciences. Over 100 Environmental Sciences Division staff members provided the workshop with research experience and student lectures and served in other capacities. Fifty-seven high school students, representing all states, the District of Columbia, Puerto Rico, Italy, Canada, Germany, Great Britain, and Japan spent 2 weeks at the Laboratory.

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 at the Laboratory under the supervision of an ORNL staff member. Ten students participated in the program in FY 1989, for a total of 22 participants since the inception of the program.

Initiatives are also being developed and expanded to involve students traditionally underrepresented in precollege programs in an effort to increase the pool of citizens who elect to pursue careers in science and engineering. An example of such a program 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 1989, SEED was expanded to include 8 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 Study 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 23 study modules that provide students with the opportunity for hands-on learning in both the life sciences and physical sciences (Figs. 50 and 51). The units are offered

Fig. 50. "Hands-on" science in the precollege program—these youngsters are discovering how "alive" pond water is.

Fig. 51. Through the study unit, "Wheels," these girls and other young students are learning basic principles of motion.

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. Since its inception in 1983, the Study Center has hosted over 18,000 participants.

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 with disabled students in the standard Study Center format. In addition, several of the study units have been modified for indoor programs and are also presented for disabled individuals.

A partnership with the Oak Ridge and other area schools has 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 serve to assist the schools in enhancing the scientific educational experiences of both students and teachers. This partnership will serve as a model 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-classmen college and university students who major in 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 program of long standing at ORNL, continues to be sought by students from the colleges of that consortium. A 10-year survey of these participants indicated that the Oak Ridge experience had a pronounced effect on their pursuit of graduate studies and career choices in the technical fields. The DOE-ER–funded Science and Engineering Research Semester (SERS) Program is now in its third year at ORNL and five other national laboratories (Fig. 52). 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 the program began. The longer term of appointment and established funding add 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 and for a total maximum term of 18 months. The Technology Internship Program, developed to enhance training for technical students in 2-year colleges, also is structured to allow longer and 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 the ORNL

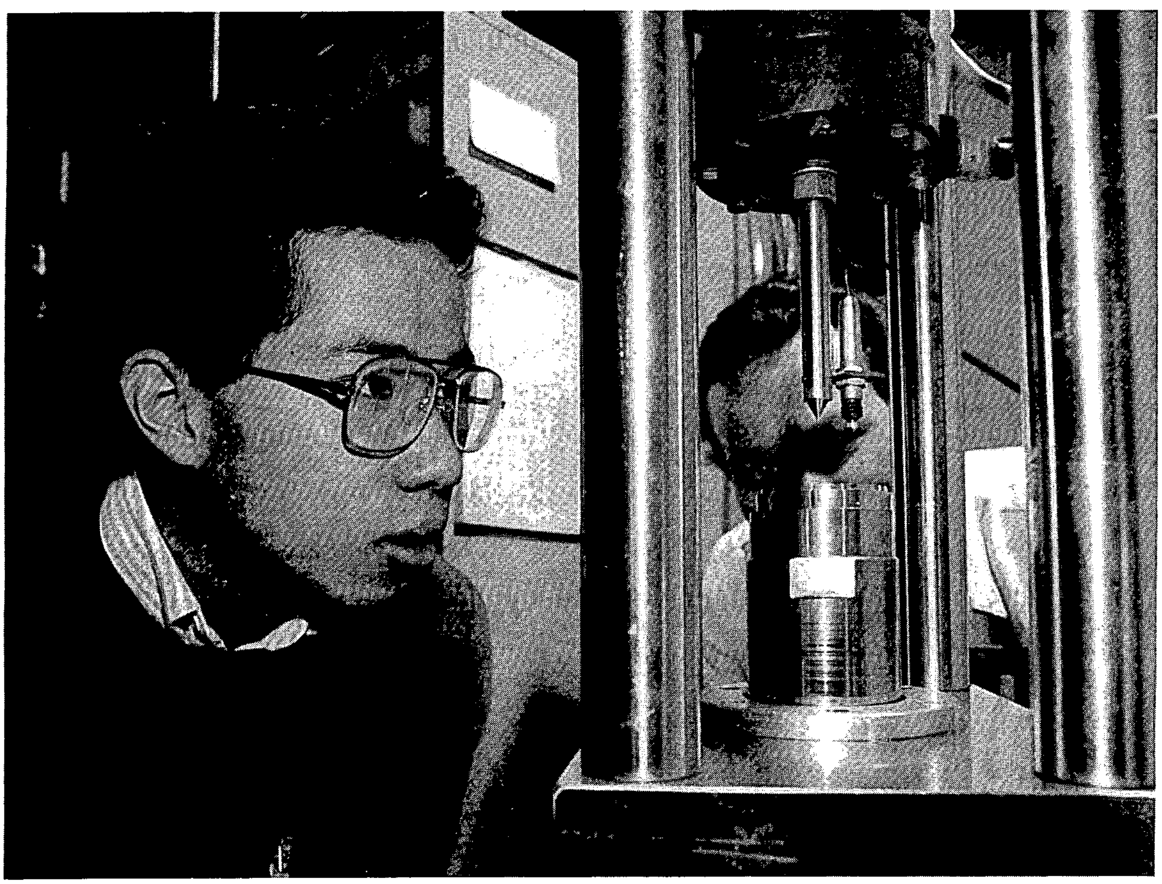


Fig. 52. Arizona State University student, Henry Wong, studies materials testing with ORNL researcher, Randy Nanstad, as part of ORNL's SERS Program.

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 ORAU Nuclear Energy Research Associates Program for undergraduates in nuclear-energy related fields began this summer. The Service Academy Research Associates (SARA) Program is another relatively new program designed to provide a summer research opportunity for rising seniors from one of the U.S. military academies. The ORAU Student Research Participation Program and the Martin Marietta Student Research Internship have, for many years, brought in about 100 summer student participants at ORNL.

Graduate Programs

Prethesis graduate students in M.S. and Ph.D. programs, M.S. and Ph.D. candidates performing thesis or dissertation research, and postdoctoral participants are appointed to ORNL through various graduate education programs. The goals of these programs are to enhance the educational experiences of these students by providing opportunities to work in laboratory situations and to use 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 thesis or dissertation work under the supervision of a graduate committee composed of representatives from their school 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.

All of these programs have led to the recruitment of employees here at ORNL and at other national laboratories and research institutions throughout the country. The ORAU Law Internship Program has recently been initiated. Desirable future high-technology developments and advanced scientific abilities will surely require legal expertise for regulation, resolution of questions, and standard setting. Experiences in a national laboratory that is involved with so many of these innovations can be a rich training ground for future legal professionals.

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

A current memorandum of understanding (MOU) in effect is with UTK, which was initiated as part of the Science Alliance. Sponsored by the state of Tennessee, this Center of Excellence at UTK operates under the auspices of the Better Schools Program.

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. Two Distinguished Scientists began appointments in FY 1989, bringing the total to 11. 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.

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 degree 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 located at ORNL are the two UTK graduate schools, the Oak Ridge Graduate School of Biomedical Sciences (ORGSBS) and the Graduate Program in Ecology. Both are in their second decade. These graduate programs provide a home for several UTK faculty.

Housed in the Biology Division at ORNL, ORGSBS 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, 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. Participation at ORNL is typically about 25 graduate and postgraduate students.

Minority Educational Institutions

ORNL continued to expand program interactions with MEIs during FY 1989. These efforts were highlighted in December 1988 when the MEI Program became a part of the ORNL Office of University and Educational Programs. The MEI Program previously reported through Martin Marietta Energy Systems, Inc., Office of Equal Employment Opportunity and Minority Program Development. This transfer highlights the increased emphasis on ORNL's efforts to expand collaborations with MEIs.

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 MOU with the University of Puerto Rico was established in FY 1988 and continues to be a highlight toward increased interactions with Hispanic institutions. During FY 1989, the MOU provided a mechanism to support 8 students and faculty members to conduct research in various ORNL divisions. In addition, although subcontract activities are not funded through the MOU, subcontract activity through ORNL divisions provides another mechanism for collaboration.

Also in FY 1989, as a part of the Historic Memorandum of Understanding and Intent and to form support for the DOE-ER Science and Technology Alliance, ORNL established a subcontract with North Carolina A&T State University (NCA&TSU). NCA&TSU, New Mexico Highlands University, and the Ana G. Méndez Educational Foundation along with ORNL, Sandia National Laboratories, and the Los Alamos National Laboratory, make up the Alliance. The intent of the Alliance is to develop a sustained program, with the combined efforts of the participating institutions, to increase the representation of Blacks, American Indians, and Hispanics in DOE's scientific and engineering programs. ORNL established an initial subcontract with NCA&TSU in the amount of $372,000 for program administration, faculty development, student development, curricula development, and other direct/indirect components as needed. Although ORNL selected NCA&TSU as its prime contact, other activities will also be ongoing with the other Alliance Educational Institutions, including assistance to New Mexico Highlands University in the establishment of an R&D library to support a planned program in technology. ORNL will donate books and magazines totaling over $17,000. Also, ORNL is assisting the Ana G. Méndez Educational Foundation in the establishment of a 5-year plan for the Computer Center. ORNL is providing a staff member to consult with the Méndez Foundation in the creation of the operating plan for the Computer Center.

Another component of the Historic Science and Technology Alliance is a collaboration between the ORNL Metals and Ceramics Division and NCA&TSU in the development of a sustained program in the materials engineering programs of NCA&TSU. Interaction between NCA&TSU and the Metals and Ceramics Division dates back several years through collaborative research subcontracts totaling more than $1 million. These research projects are credited with aiding several minority students in obtaining graduate degrees in mechanical engineering. This collaboration has also led to the inclusion of NCA&TSU as a partner, along with the Metals and Ceramics Division, the University of Dayton, and the National Bureau of Standards, in a DOE-sponsored research program on the study of ceramic technology for advanced heat engines.

ORNL also has several MOUs with other MEIs, including one with Southern University that included faculty and student research appointments at ORNL and the Y-12 Plant during the summer of FY 1989. Two faculty members and two students received research appointments; also, R&D subcontracts totaling $220,000 were committed to Southern University. ORNL continued to collaborate with Tuskegee University with R&D subcontracts totaling $118,000 and support of two students and one faculty member for summer internships during FY 1989.

Efforts continue to identify excess equipment that might be used on MEI campuses to enhance their research capabilities. During FY 1989, through various interactions with MEI faculty, over $300,000 worth of equipment was loaned to MEIs.

Energy Systems is also working with ORAU, the Southeastern Consortium for Minorities in Engineering, and various precollege school systems, seeking to increase the number of minorities and women who elect science and engineering programs in college.

Proposed Programs

Several new initiatives in support of university and educational programs are expected to be funded by the KE program in FY 1990. These initiatives include the following:

- Several national teacher training programs are expected to be expanded or modified. TRA and STAR are expected to expand to involve more than 40 teachers during the summer of FY 1990.
- With ORNL serving as the lead laboratory in

partnership with four other participating DOE laboratories, an NSF grant proposal for a multidisciplinary training program for teachers in grades kindergarten through eight has been submitted. Evaluation and networking are key components of this initiative. The program is expected to serve over 400 teachers in a 3-year period involving "hands-on" activities that will impact conventional science curricula.

- ORNL will also participate in a local pilot program, Science-By-Mail, which will match individual pupils at selected area schools with scientists, engineers, and mathematicians who will work with them on various projects. During the first year of the program, Science-By-Mail will focus on students in the fourth and fifth grades. Area students will be recruited to participate in the program.
- ORNL will expand the Summer Seminar Series Program to become an integral element of the summer education program. Attendance at the Summer Seminar Series will be a component for all teachers participating in the teacher research programs and high school students participating in the SEED program. Participation will allow students and faculty to have an overview of research at ORNL. All speakers will have educational linkages and, as often as possible, will be drawn from the pool of mentors for the summer research participants.
- MOUs with the University of Puerto Rico 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 to DOE.
- 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 also begin to investigate the feasibility of sponsoring regional high school science bowls. A similar collaboration would involve the sponsorship of a Careers in Science and Technology Workshop for regional minority students to encourage them to continue in pursuit of careers in science and technology and to inform them about various opportunities and mechanisms to do so.
- ORNL will also continue to increase interactions with top academic institutions. Toward this goal, ORNL has established MOUs with Duke University and the University of California–Santa Barbara. ORNL is also expanding its interactions with the service academies through the SARA program, thus increasing numbers of students from the U.S. Naval Academy, the U.S. Military Academy, and the U.S. Air Force Academy. Faculty from service academies will also be encouraged to participate.
- The number of university research participants is expected to increase in FY 1990 with the continuation of the Oak Ridge Science and Engineering Research Semesters (ORSERS). When fully operational, the ORSERS program would support several hundred students annually for research participation and training, mostly during the academic year. A goal for the program is to have the students and faculty housed in a multipurpose building to be constructed in central Oak Ridge.

Summary

The university and educational programs will continue to grow significantly. It is therefore important that a facility be developed that meets the needs of the growing precollege and university programs. ORNL will continue to involve new groups in these 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, but opportunities for new initiatives still exist.

The ORNL University and Educational Programs Office will continue to grow and to be a model for other federal laboratories and corporate entities in improving 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.

User Facilities

ORNL has served for many years as the steward of numerous, highly sophisticated research facilities. These user facilities are designed to serve both the technical community and DOE missions by minimizing unnecessary duplication, promoting beneficial scientific interactions, and making the most effective use of costly and, in many cases, unique equipment (Fig. 53).

Visiting scientists using these facilities are an important source of external interactions for ORNL. In 1988, 417 external researchers and 279 ORNL scientists conducted experiments at ORNL user facilities (Table 36 and Fig. 54).

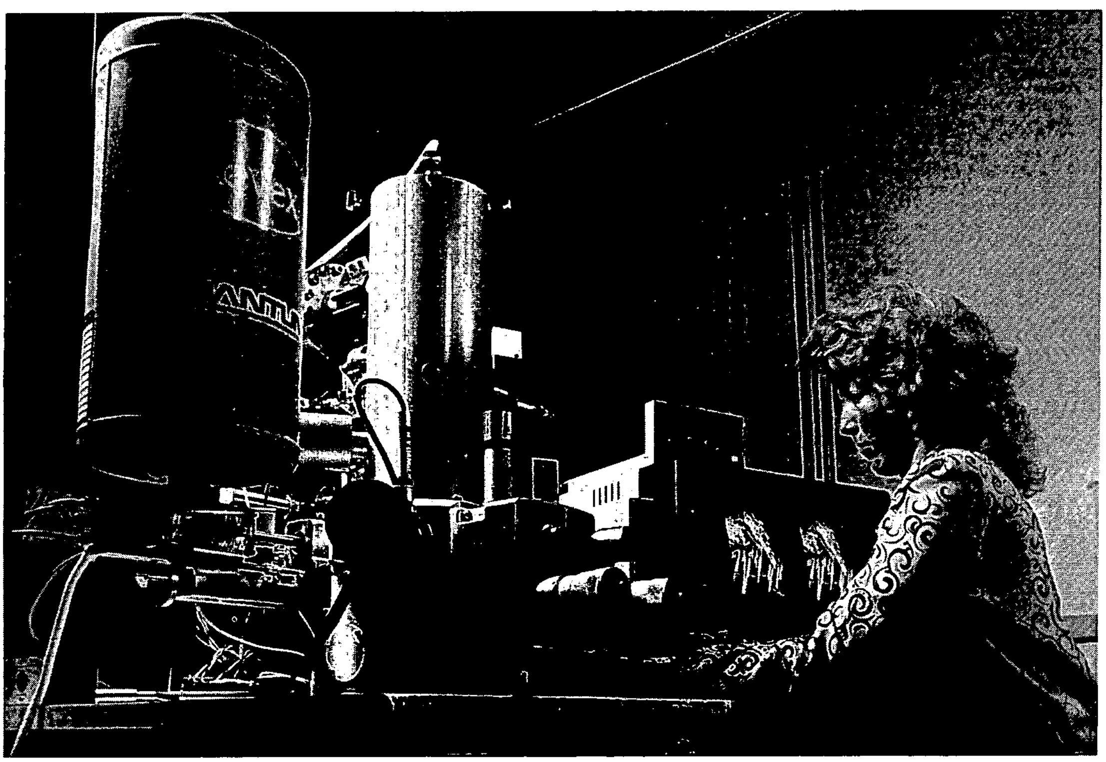


Fig. 53. Denise Sammons using the Hitachi S-800 scanning electron microscope to determine the morphology of ceramic composite fracture surfaces. This instrument is one of a suite of instruments available for industrial and university users as a part of the High Temperature Materials Laboratory user program sponsored by the Office of Transportation Systems.

Table 36. Experimenters at designated user research facilities in FY 1988

	U.S. Gov't Lab.[a]			University			Industry			Foreign			Total		
	Exp.	Org.	% Use[b]	Exp.	Org.	% Use[b]	Exp.	Org.	% Use[b]	Exp.	Org.	% Use[b]	Exp.	Org.	User days
Holifield Heavy Ion Research Facility (HHIRF)	40	4	39.3	96	33	46.0	1	1	1.0	29	18	13.7	166	56	1,301
National Environmental Research Park	48	4	42.5	62	15	42.5	3	1	2.0	1	1	0.1	122[c]	27[c]	3,512[c]
High Temperature Materials Laboratory (HTML)	103	4	86.9	13	8	6.0	9	6	7.1	0	0		125	18	1,131
Surface Modification and Characterization Laboratory (SMAC)	49	7	74.4	36	16	20.6	10	6	1.0	6	5	4.0	101	34	1,693
Shared Research Equipment (ShaRE)	28	1	69.7	31	11	23.3	3	2	3.3	2	2	3.7	64	16	932
National Center for Small-Angle Scattering Research (NCSASR)[d]	11	2	32.9	23	15	47.5	7	3	11.2	3	2	8.4	44	22	295
EN Tandem Van de Graaff	14	1	38.9	19	4	57.5	0	0		6	3	3.6	39	8	1,261
Oak Ridge Electron Linear Accelerator (ORELA)	16	1	83.9	4	3	14.0	2	1	1.5	2	1	0.6	24	6	1,990
Bioprocessing Research Facility	0	0		6	5	44.9	1	1	1.1	2	1	54.0	9	7	176
Roof Research Facility	0	0		1	1	76.9	1	1	23.1	0	0		2	2	65
Neutron Scattering Facility[d]	0	0		0	0		0	0		0	0		0	0	0
Health Physics Research Reactor (HPRR)[d]	0	0		0	0		0	0		0	0		0	0	0
Low Temperature Neutron Irradiation Facility (LTNIF)[d]	0	0		0	0		0	0		0	0		0	0	0
Totals (experimenters and % use[b])	309[a]		57.6[a]	291		32.4	37		2.3	51		3.7	696		12,356

[a]Includes 279 ORNL users (55.2% of use).

[b]% use = % of total user days.

[c]The totals for the National Environmental Research Park include 8 users from 6 organizations (12.9% of the park's use and 4% of the total research facilities' use) that are not covered by the four categories listed in the table.

[d]Facility affected by DOE reactor shutdown order.

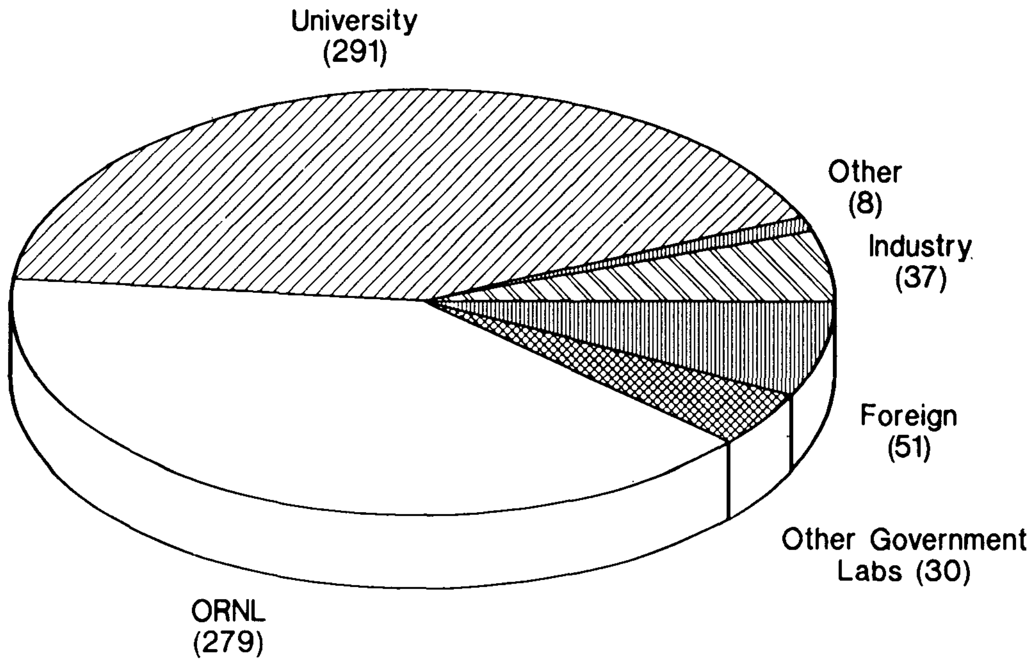


Fig. 54. Participants at ORNL user facilities (FY 1988).

Traditionally, more than one-half of these external researchers are university scientists. Figure 55 shows trends in the number of outside users of our facilities since 1979. Other facilities are being considered as future designated user facilities based on the extent of outside interest in their unique capabilities. The Gammasphere project (see Initiatives) represents a significant enhancement of the HHIRF and will attract a large number of new users to ORNL for nuclear physics research.

A major factor influencing the use of user facilities from FY 1987 through FY 1989 was a result of DOE's order on March 26, 1987, to shut down all research reactors at ORNL. This order directly affected the following facilities:

- the Health Physics Research Reactor (HPRR),
- the National Center for Small-Angle Scattering Research (NCSASR),
- the Neutron Scattering Facility (NSF), and
- the Low-Temperature Neutron Irradiation Facility (LTNIF).

In addition, DOE's decision to place the Bulk Shielding Reactor (BSR) into cold shutdown condition has led to the elimination of the LTNIF. Restart of the High Flux Isotope Reactor (HFIR) and the Tower Shielding Facility are expected in FY 1990, to be followed by restart of the HPRR. With restart of the research reactors the decrease in numbers of users for the past 3 years should be reversed.

To facilitate a more user-friendly environment at ORNL, encourage cooperative R&D, and provide greater access to user facilities by external scientists and organizations, a centralized Office of Guest and User Interactions (OGUI) was established during 1989. The OGUI was formed by consolidating existing personnel and functions performed by the Foreign Nationals Office, Guest Services Office, a member of the Contract Administration Office, and additional support staff into a central organization. A member of the Office of General Counsel provides legal assistance as needed to support the goals of the OGUI. The staff of the OGUI works with DOE/Oak Ridge Operations, ORNL staff, and external researchers to develop and implement streamlined procedures and much needed services related to the

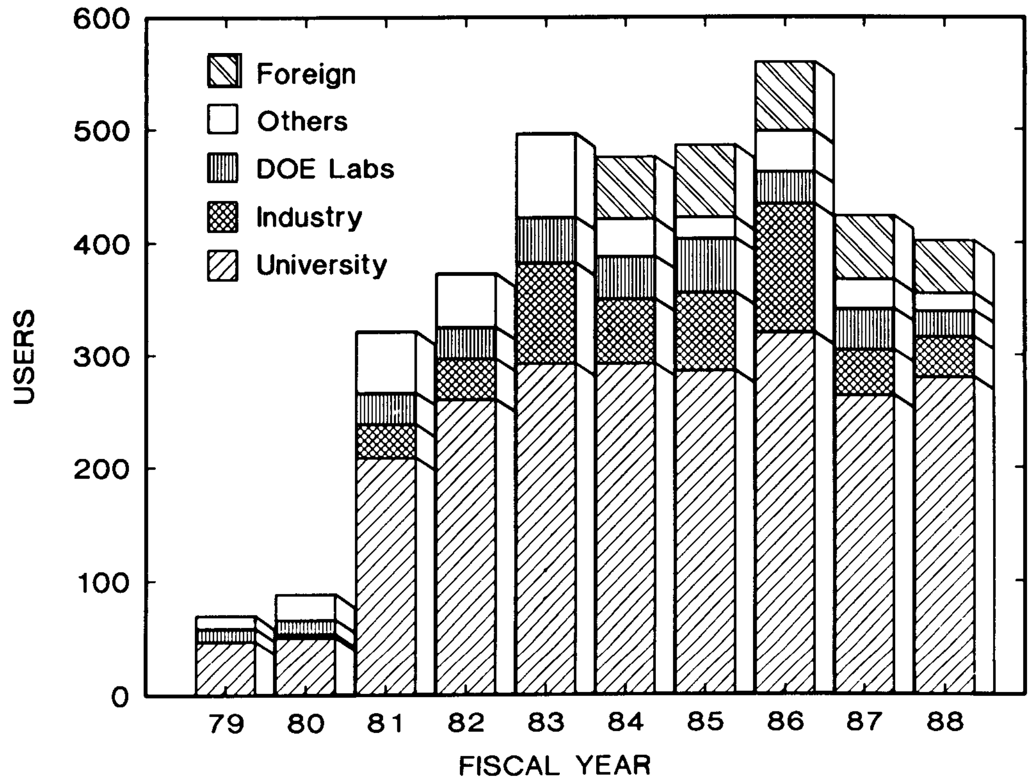


Fig. 55. Number of outside users of ORNL facilities.

performance of research at ORNL by external scientists and engineers.

Technology Transfer

To a growing extent, the exceptional scientific and technical developments that emanate 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 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. Legislative acts and presidential decrees have created more favorable laws and policies for integrating government-funded research into the country's economy. However, institutions such as ORNL must continue to search for creative ways to transform good intentions into reality.

Effective technology transfer is a "contact sport," made possible by providing the Laboratory and industry with reasonable incentives to make such contact happen. In the area of patent licensing, our inventors are motivated by seeing their developments make an impact in the marketplace and by receiving their share of royalty proceeds. A protected patent position motivates companies to invest in product development.

Cooperative research efforts with industry, on either a one-on-one basis or through R&D consortia, help each participant focus on national issues and scientific priorities. As partnership development grows, it promotes a cross-fertilization that results in the generation of new ideas and technologies originating from both the public and private sectors. These efforts will assume a more prominent role at the Laboratory in the years ahead.

The importance of licensing and partnership development is reflected in the missions of the ORNL technology transfer program. The mission of the licensing program is to license commercially valuable technologies by identifying technologies with market potential, developing strategies for their transfer, and negotiating licenses directly with industry. The partnership development program bridges the gap between government-funded R&D and commercialization, promoting industrial use of Oak Ridge facilities, expertise, and technologies through cooperative development efforts with individual firms or industrial consortia. Long-term commitments to these initiatives will help us maintain leadership in a growing effort to bolster U.S. competitiveness in the global marketplace by promoting rapid commercialization of new technologies.

Licensing Oak Ridge Technologies

Recent emphasis of our technology transfer activities has been in licensing activities because licensing patented technologies has the highest potential for creating near-term impact on the U.S. economy. We are finding, however, that technologies that have the greatest potential frequently require complex arrangements, which often include more than one party. Such a case is the triple effect absorption chiller, which was recently licensed to the Trane Company. This agreement involves Trane, which will develop it, and the Gas Research Institute of Chicago, which will jointly fund the development program. The new air conditioner uses a natural gas flame to operate the cooling cycle; therefore, it is more economical to operate than conventional electric air conditioners. It will alleviate the demand on electric utilities during the summer's peak demand periods by using natural gas, which has its highest demand period during the winter months. The efficiency of this system is shown in Fig. 56. The

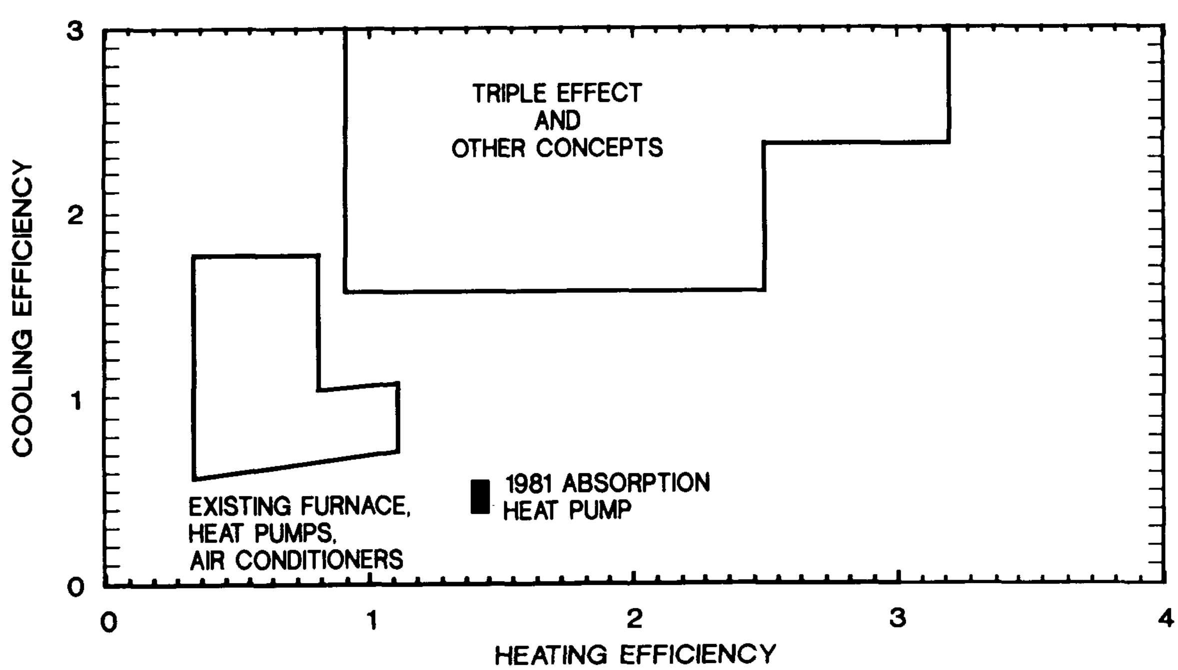


Fig. 56. Absorption cycles have been identified with performance potential well beyond current technology.

absorption chiller has the potential for great impact on both the U.S. economy and national energy usage. We feel that small technologies such as the Africanized bee detector are equally important to our program because many of our technologies are appropriate for small or start-up companies. This year the bee detector was licensed by the inventor, who is now producing and selling the product.

Currently, Energy Systems has 36 license agreements. Approximately one-half of these are in the materials area. To broaden our licensing base, future emphasis will be directed toward increasing the number of licenses in waste management and analytical instruments, advanced manufacturing and intelligent processing, bioprocessing and chemical separations, and advanced energy systems. Figure 57 shows the technologies presently licensed.

Incentives

Our experience shows that government policy changes instituted in the past few years can accelerate the rate of technology transfer from government facilities to industry. Granting substantial patent rights to us provides the

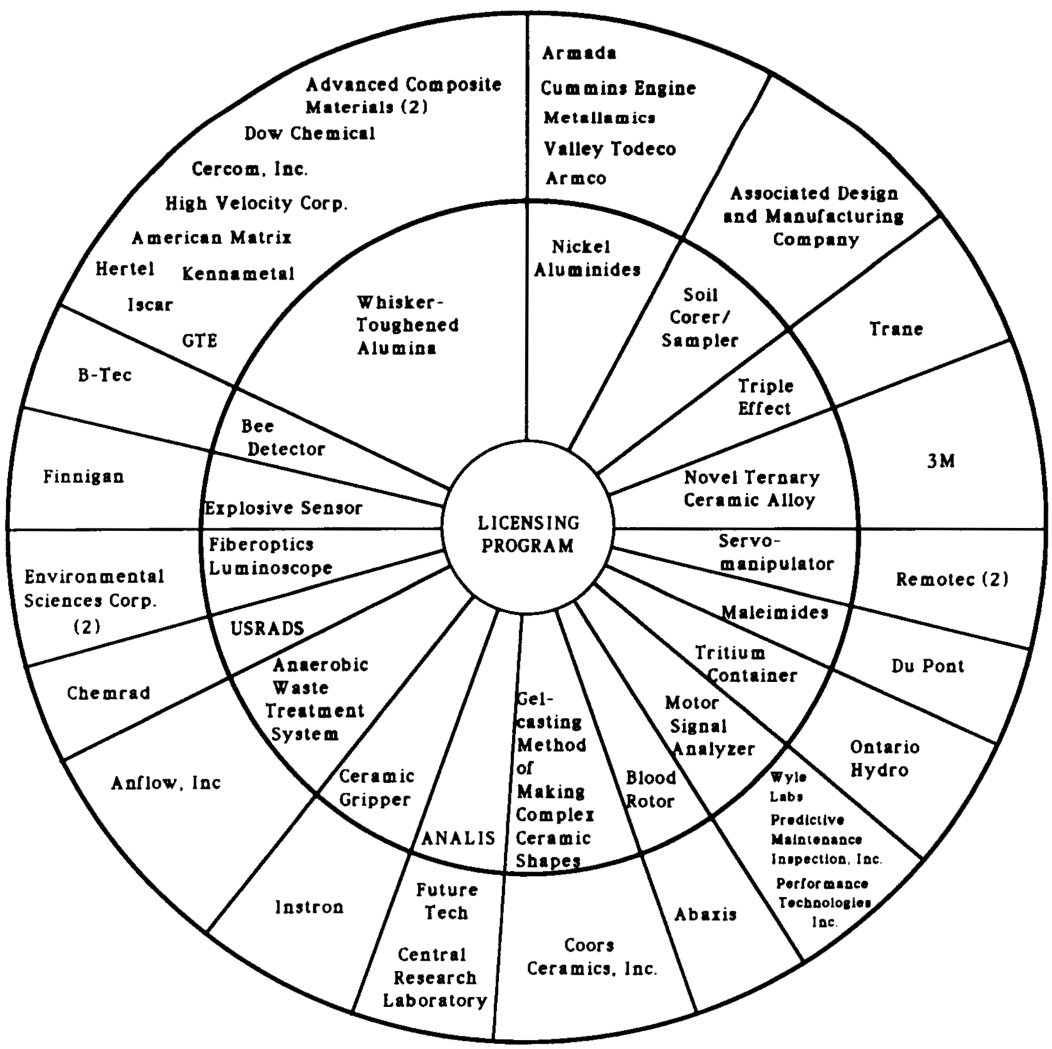


Fig. 57. Energy Systems has 36 license agreements.

incentive to work aggressively toward commercialization of the research. Martin Marietta Corporation derives no monetary benefit from technology transfer royalties. The royalty fund is used to further technology transfer in several ways:

- recovering patenting and licensing costs,
- rewarding inventors and technical staff,
- funding technology maturation projects, and
- contributing to nonprofit technology transfer organizations.

The royalty proceeds received also provide the means to produce sample materials or prototype instruments to demonstrate the technology to industries and take other actions (such as organizing workshops or seminars) that will speed the technology's commercialization.

The originating organization is best able to facilitate this rapid technology transfer and to provide the opportunities for interaction between laboratory inventors and their commercial counterparts in a particular area of technology development. Energy Systems' licensing policies provide incentives for increasing inventor contacts and interactions with companies interested in commercializing their innovations and may, in some cases, encourage private funding for continued development of the technology by the inventor at a government facility.

Industry-Laboratory Partnership Projects

The process of developing and implementing partnership agreements is undergoing a gradual evolution at ORNL. The original stage of 2 or 3 years ago could be characterized as "ad hoc contracting," in which technology transfer opportunities were identified and special forms of agreement were developed to accommodate each specific situation. As a result, an array of new technology transfer mechanisms was developed. Now, in the current stage of evolution of technology transfer, these "specimen" agreements are used (with some modifications) as the basis of contractual arrangements for new interactions. Currently, all partnership agreements require DOE approval.

Significant accomplishments have been achieved within this framework. Several specific examples of programs undertaken during the past fiscal year illustrate the directions taken in these efforts. Agreements were signed with two Tennessee universities for development of parallel-processing computer systems. An agreement was signed with the American Society of Heating, Refrigeration, and Air-Conditioning Engineers for funding on alternative refrigerant research for residential refrigerator/freezers. A major consortium of U.S. semiconductor manufacturers is involved in research programs to optimize the operating regime of an ORNL-invented microwave ion source for use in thin-film integrated circuit etching processes.

To advance beyond this point in technology transfer, further development and modification of the contractual terms and conditions will be required. It is expected that even more efficient mechanisms for technology transfer will be defined, and the final stage of evolution (within the existing legislative and regulatory framework) will be in place. These changes would involve more standardization of forms of agreements, with terms and conditions more acceptable to industry, and a reduction in approval cycle times. If any of the significant technology transfer legislation currently before Congress were to be approved, the process would move to a new plane, but once again on a more exploratory basis.

In addition to trends toward more standardization and expedience of partnership agreements, several other improvements in technology transfer procedures seem imminent. First, more and more integration of licensing activities and partnership research activities is occurring. Patent licensees are returning to ORNL with additional development needs, which can be met only by the Laboratory. This can be met in two ways: through maturation projects and through partnership agreements. Industry partners are seeking background patent rights as part of their contractual R&D package. Second, it is becoming apparent that to be successful in transferring technology, we must develop an overall strategic plan reflecting analysis of all the economic, marketing, and technical factors that bear on the application of the technology in industry. ORNL expects to move its technology transfer program in these directions during the coming fiscal year and beyond.

High-Temperature-Superconductivity Pilot Center

High-Temperature-Superconductivity Pilot Center (SPC) programs at Oak Ridge, Los Alamos, and Argonne National laboratories were initiated by DOE in 1988. These experimental programs in public/private cooperation were implemented to make the resources and expertise of the national laboratories available to private industry to speed up the process of developing commercial applications for high-temperature superconducting materials and devices.

To encourage industrial participation in the pilot center program, DOE provided a "model" cooperative agreement that had been developed with input from both the laboratories and private industry. In addition, the pilot centers were given some flexibility to negotiate terms acceptable to both the business partner and DOE/ORNL. New provisions include an automatic waiver of patent rights to both the contractor and big business and the capability to protect, for a limited time, technical data or computer software that has near-term commercial value and is necessary for successful commercialization.

The objectives of the ORNL High-Temperature SPC, which received authorization from DOE on November 15, 1988, are to (1) facilitate cooperative superconductivity R&D by ORNL, industry, and universities; (2) optimize the utilization of facilities, expertise, and program resources at ORNL for the benefit of all participants; (3) develop streamlined contractual, patent, and intellectual property right policies that will encourage private-sector participation and provide appropriate competitive advantages to the participants; and (4) coordinate the ORNL activities with the other pilot centers, other national laboratories, other government agencies, university centers, and industry groups.

Through August 1989, the ORNL High-Temperature SPC had signed cooperative agreements with General Electric, Westinghouse, Corning, DuPont, American Superconductor, Consultec, American Magnetics, and Textron for a total value of $2.4 million, with an average match of DOE to private funds of 1 to 1.5. The project descriptions include material characterizations, fabrication of bulk conductors, aerosol reactor powder preparation, microwave sintering, and various deposition processes for preparation of thin films. Principal investigators are located in ORNL's Metals and Ceramics, Solid State, Chemistry, Energy, and Engineering Technology divisions.

The three pilot centers have formed an Interlaboratory Steering Group, which meets quarterly. DOE has a corresponding group composed of both operations offices and Headquarters personnel that meets concurrently. The separate sessions are concluded with a joint meeting of the two groups. This arrangement facilitates communication among the pilot centers and with DOE.

Tennessee Center for Research and Development

The Tennessee Center for Research and Development (TCRD) is a regional mechanism for conducting market-driven applications developments on the technologies developed in East Tennessee, specifically, Energy Systems, the Tennessee Valley Authority (TVA), and UTK. It is now operating with a budget of several million dollars and has contracts from the Electric Power Research Institute, industry, and TVA. Overall management has been provided on a volunteer basis, but this arrangement is no longer sufficient. To provide funds for general administration activities, TCRD's board decided to ask its founding members—Energy Systems, TVA, and

UTK—for an annual membership fee of $100,000. Of this amount $50,000 will be paid out of the royalty fund; Energy Systems is asking for the other $50,000 to come out of our operating funds budget. This private-sector vehicle for interacting with industry is needed to enhance the effectiveness of our technology transfer program. TCRD has greater procurement flexibility and the ability to raise private investor funding to conduct applications development.

Productivity Indicators

One productivity indicator is the amount of product sales that results from our licensed technologies. We expect that product sales will increase from $30 million to $150 million in 5 years. Product sales are also a good indicator of new economic activities. Each $100,000 in sales represents a new job in the private sector.

Although Oak Ridge has been historically known as a one-company town because of the DOE facilities, a significant number of the new industry relocations and expansions have occurred because of the increased ability to access the technologies in Oak Ridge. Companies relocating or expanding in Oak Ridge feel that it makes good business sense to be located near the source of the technologies they have acquired. A recent study done by the Oak Ridge Chamber of Commerce dramatically shows the impact on the local economy caused in part by the aggressive technology transfer program (Fig. 58).

Technology transfer results are also shown in Table 37 and Figs. 59 through 62.

Technology Transfer Program Support

Information Dissemination

Although an information dissemination program does not cause licenses or cooperative agreements to be consummated, it is necessary to keep customers aware of new technologies available from the Laboratory. Energy Systems' Office of Technology Applications (OTA) hosts conferences and workshops on technology transfer, attends trade shows, and publishes Technology Applications Bulletins, which inform industry and state and local government of our latest

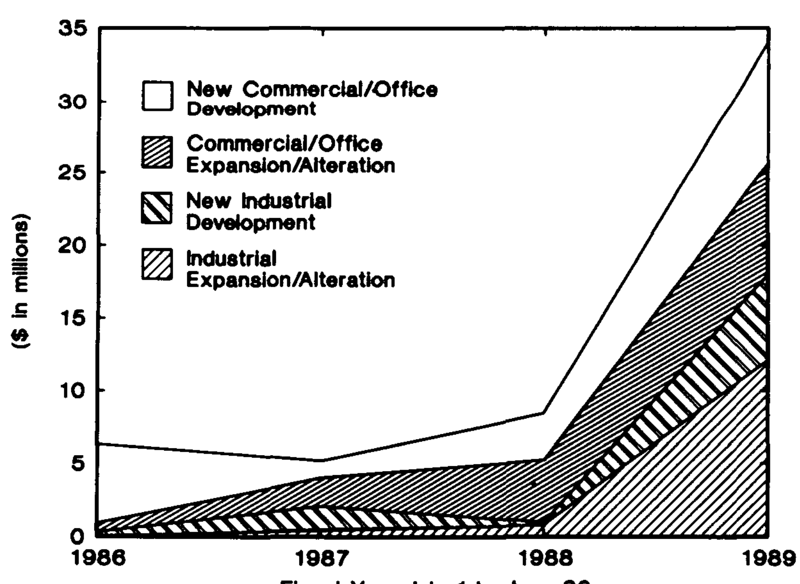


Fig. 58. Value of new economic development activity in Oak Ridge.

Table 37. Technology transfer results

	Fiscal year 1988	1989	1990 (projected)
Patent applications	36	32	37
Patents granted	26	35	36
Licenses issued	12	9	20
License income[a]	204	228	400
New companies	2	1	4

[a]Dollars in thousands.

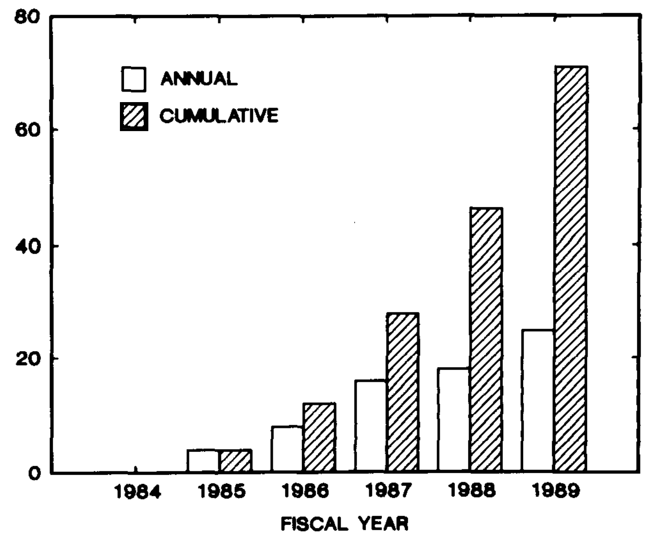


Fig. 61. Rights received from DOE.

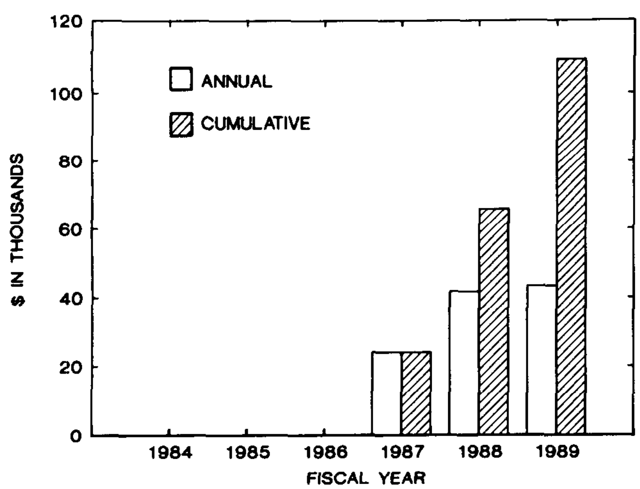


Fig. 59. Royalties paid to employees.

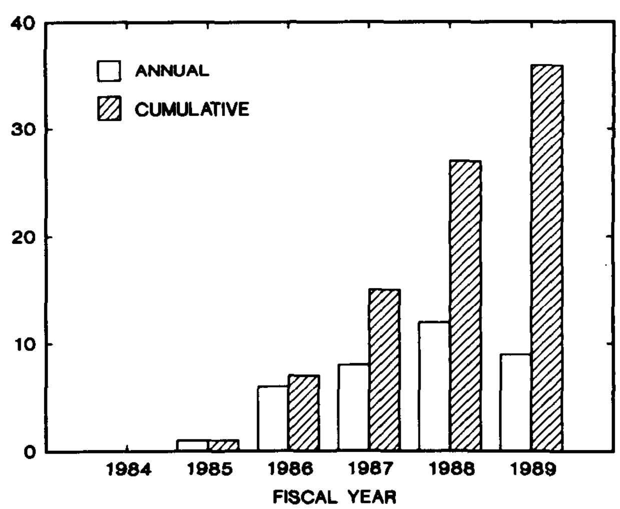


Fig. 62. Active licensing agreements.

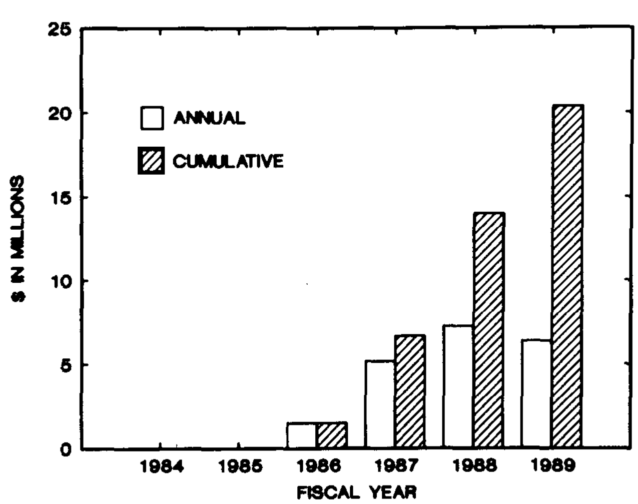


Fig. 60. Licensed product sales.

technologies and licensing opportunities. We have also had over 20 visits from personnel of other laboratories who wish to learn more about how we manage the technology transfer program. This year we published a Technology Transfer Handbook that informs Energy Systems employees of their responsibilities and opportunities in technology transfer. An increased emphasis in the past year has been placed on outreach to the region immediately surrounding Oak Ridge. A large portion of our past licenses have been to regional industries; however, we find that many local entrepreneurs are unaware of the availability of technologies and assistance from the Laboratory. A series of articles authored by OTA staff have appeared in local papers. We have greatly increased the number of speaking engagements at local business organizations and have continuing involvement with regional economic development organizations, such as Chambers of Commerce and the Tennessee Department of Economic and Community Development.

Business Management and Budget

Monitoring licensing documentation and royalties fees from industry and to inventors has created a need for a management information system to track receipts. The new system documents invention status from the point of disclosure through evaluation, waiver of rights from DOE, application for patent, licensing strategy, licensing negotiation, and finally to receipt and use of royalties.

The budget for the Technology Applications program for FY 1989 was $1.3 million; the number of FTEs supported was 14.8 (Table 38).

A unique aspect of the OTA program is in its use of MBA students from The University of Tennessee School of Business to do marketing studies, which assist in determining marketing potential for new technologies. We have found this to be invaluable to our program; it also gives the students valuable marketing experience in dealing with high-tech products.

Subcontracting and Procurement

Subcontracting is scheduled to increase significantly in FY 1990 because of an increase in environmental restoration activities. This trend should continue through the early 1990s (Table 39). The increase in transfers to other DOE facilities in FY 1989 and subsequent decrease in FY 1990 results from the changing level of effort associated with the cesium stabilization work being performed at DOE's request for the state of Georgia.

Table 38. Estimated staffing and expenditures for the Office of Technology Applications[a]

	Fiscal year							
	1988	1989	1990	1991	1992	1993	1994	1995
Funding ($ in millions)								
OTA	0.93	1.29	1.66	1.65	1.76	1.83	1.92	2.00
Other[b]	10.93	11.50	12.15	12.76	13.40	14.07	14.77	14.77
	11.86	12.79	13.81	14.41	15.16	15.90	16.69	16.77
Staffing (FTEs)								
Professional								
OTA	8	10	10	10	10	11	11	12
Other[b]	55	55	55	55	55	55	56	56
Support	3	4.8	4.8	4.8	4.8	4.8	4.8	4.8

[a]These funds are for the ORNL Office of the Martin Marietta Energy Systems, Inc., Office of Technology Applications, which includes ORNL, the Y-12 Plant, ORGDP, and Paducah Gaseous Diffusion Plant.

[b]Estimated.

Table 39. Subcontracting and procurement
($ in millions)

	Fiscal year		
	1988	1989	1990
Subcontracts and procurement with universities	19.9	19.6	19.6
All other subcontracts and procurements	110.2	100.8	119.9
Transfer to other DOE Facilities	4.1	12.9	6.1
Total	134.2	133.3	145.6

Table 40. Small and disadvantaged business procurement
[$ in millions—budget authorization (BA)]

	Fiscal year	
	FY 1988	FY 1989
Procurement from small and disadvantaged businesses	58.1	59.3
Percent of total procurements	43.3	44.5

A significant percentage of the Laboratory's procurement goes to small and disadvantaged businesses (Table 40).

Human Resources

Laboratory Personnel

The diverse nature of the work performed at ORNL demands a diverse, multidisciplinary technical staff and an equally diverse support and services staff (Fig. 63). Scientists and engineers constitute the bulk of the Laboratory's current professional staff, representing about 75% of the total number (Table 41). Of the 788 professional scientists on staff, 515 hold the Ph.D. degree. Among engineers, 234 of the 764 on staff hold Ph.D.'s. Master's degrees are held by another 355 professional scientists and engineers.

The engineering disciplines in which our staff are primarily trained are chemical, mechanical, and nuclear. There are also about 60 mathematicians, about 590 other physical scientists, about 240 life scientists (biomedical and environmental), and about 50 social scientists. In 1988 administrative responsibility for Energy Systems' multisite organizations were centralized

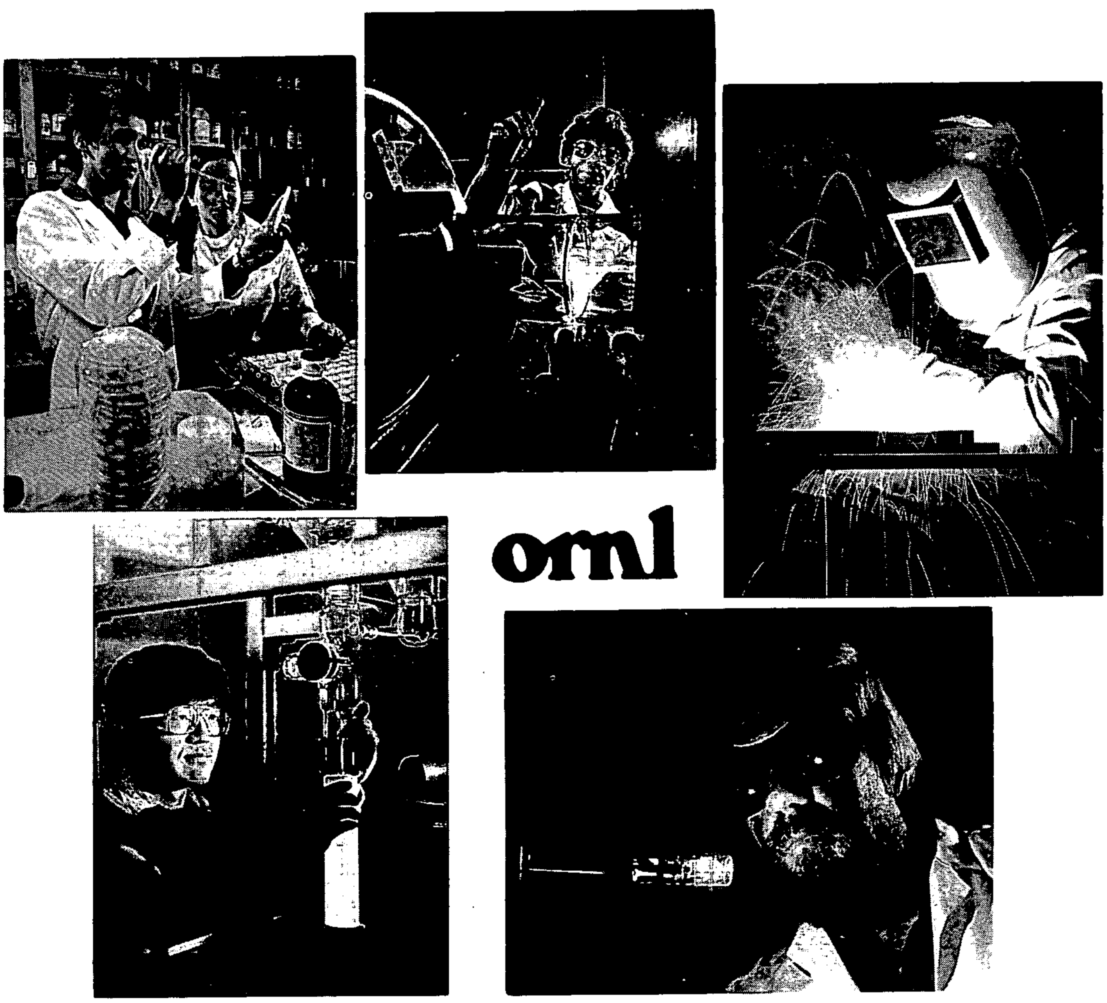


Fig. 63. ORNL has a diverse, highly skilled scientific, technical, and support staff.

Table 41. Oak Ridge National Laboratory staff composition, CY 1988

	Ph.D.	M.S./M.A.	B.S./B.A.	Other	Total
Professional staff					
Scientists	515	136	125	12	788
Engineers	234	219	258	53	764
Management/administrative	106	76	120	61	363
Other	30	53	51	22	156
Total professional staff	885	484	554	148	2071
Support staff					
Technicians	0	6	110	478	594
Other					
Union employees (includes crafts, laborers, etc.)	0	0	9	1003	1012
Supervisors of union employees, etc.	0	5	76	753	834
Total support staff	0	11	195	2234	2440
Laboratory total staff	885	495	749	2382	4511

under their functional vice presidents. Engineering, Computing and Telecommunications Division (C&TD), Administrative Services (including library, technical publications, graphic arts, and printing support), and Procurement are among these groups. Currently, about 280 of the Engineering staff, 270 C&TD staff, and 226 Administrative Services staff members work on ORNL programs.

Augmenting the population and broadening the Laboratory's base of expertise are some 2300 guests. Guest assignments at the Laboratory may last anywhere from a few months to a year or more. About 350 of these guests represent energy-related foreign research organizations; the remainder represent U.S. colleges and universities, as well as U.S. government and industry.

In 1984 ORNL and The University of Tennessee, Knoxville, established a joint initiative to build on existing academic and research strengths—the Distinguished Scientist Program. Currently, there are 11 scientists or engineers holding Distinguished Scientist appointments. The purposes of the Distinguished Scientist Program are (1) to attract to the two institutions a select additional number of scientists and engineers of national and international stature, (2) to enhance the interaction of the two institutions at the highest level of competence, and (3) to further strengthen the quality of science, education, research, and industrial technology development in the East Tennessee area.

Improving and Maintaining Continuity of Staff Quality

At present the Laboratory has a 66% average acceptance rate overall for offers made to Ph.D.'s (53% for engineers, 73% for all others). The acceptance rate for B.S. and M.S. candidates is also 66%; however, the competition for such candidates is becoming increasingly stiff, as evidenced by the nearly 10% decline in the acceptance rate from a 5-year high of 80% in

1987. To ensure the continued high caliber of those being hired, the Laboratory is designing a set of hiring guidelines that define for staffing personnel the academic and professional characteristics being sought in new hires. Additionally, an ad hoc review has been proposed 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 high-caliber personnel but also to keep them. To keep quality staff, ORNL tries to provide a suitable environment for research, to provide opportunity for growth, and to reward excellent performance. One way that Energy Systems recognizes outstanding performance is by presenting annual awards in various categories; publications, technical achievement, management support service, inventions, operational performance, and administrative/technical support.

Recent studies addressing the changing demographics of the country's work force, especially as relates to those being trained in the sciences, suggest that a more nontraditional work force is on the horizon. As more of these nontraditional workers enter the job market, it will be necessary for industry to adapt 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, and the disabled. The Laboratory, and Energy Systems as a whole, are already instituting some of the kinds of 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. This, in turn, affords employees a greater flexibility in accommodating the demands of dual-career households. Such flexibility is especially important for families in which dependent care—either of young children or of elderly or ailing adults—must be considered. Policies such as these should enable more women (typically the primary care-givers) to remain in or consider entering the work force.

Recent statistics show that fewer American students are choosing to study science and engineering fields. This decline in enrollments is especially critical among minority students, specifically blacks and Hispanics. Through its University and Educational Program, the Laboratory is developing new and innovative approaches that it is hoped will encourage more students to enter science and engineering programs, and subsequently, to choose energy-related careers. These approaches include

- R&D subcontracts with universities,
- faculty and student research participation appointments,
- memoranda of understanding with a number of minority educational institutions, and
- participation in the Science and Technical Alliance.

Through such activities, the Laboratory is able to reach students early in their college careers and to provide positive role models and exciting, perhaps otherwise unattainable hands-on science experiences.

If the trend toward fewer students in science is to change, there must be an even earlier effort to provide science experiences beyond what is traditionally offered by our schools. The precollege activities component of the University and Educational Program has a full-time staff person devoted to its implementation and continued development. In addition to its school-year activities, the program also has summer projects that involve high school students and high school teachers. Participation in these activities by minority and female students and teachers is both encouraged and expected. One other avenue the Laboratory has for reaching younger minority students is through Energy Systems' participation, via its Equal Employment Opportunity organization and in conjunction with Oak Ridge Associated Universities, in the Valley Alliance for Minority Achievement Challenge program.

As mentioned earlier, disabled Americans will probably assume a greater role in the work force of the future. The Laboratory will continue its heightened emphasis on the recruiting and hiring of qualified disabled candidates. This is in keeping with Energy Systems President Clyde Hopkins' role as a member of the Executive Committee of the (U.S.) President's Committee on the Employment of People with Disabilities. It also reflects Energy Systems' sensitivity to 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 additional academic goals. This program goes far to ensure within the Laboratory population the proper availability, optimum utilization, and continuing welfare of employees who are best able to contribute to the achievement of the Laboratory's objectives, both present and future.

The Laboratory also provides in-house development programs that are 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. Thus, the internal training offered by the Laboratory is being expanded to meet the additional, specialized training needs that accompany this increased emphasis. 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 to manage the "new majority" that will begin to emerge in the 1990s and will continue beyond.

Affirmative Action (AA) is not an adjunct to but an integral part of all personnel functions and activities of the Laboratory. The ORNL AA office is a department within the Personnel Division, and the AA Program Site Manager reports directly to the ORNL Personnel Director. A primary responsibility for the AA site manager is to track and keep Laboratory management informed as to the progress being 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. 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. The program also provides the opportunity for an employee to become better acquainted with the larger 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 upward mobility plans.

Exploratory R&D Program

The principal objective of the ORNL Exploratory Studies Program is to provide financial support for innovative research and development 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 5000.1, Change 1, "Guidelines for the Use of R&D Exploratory Funds," dated December 13, 1983.

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. Approved FY 1989 budget was $1.6 million for the Seed Money Fund and $5.4 million for the Director's R&D Fund, for a total of $7 million. This total amounts to approximately 1.5% of the total operating budget of ORNL, including the Work for Others program. Table 42 provides authorized funding for fiscal years 1988, 1989, and 1990 (projected).

Proposals for Seed Money projects are accepted directly from the Laboratory's scientific and technical staff (with management concurrence) at any time of the year and are selected for funding with the assistance of a Proposal Review Committee composed of representative scientific and technical staff. Director's R&D Fund proposals are solicited in June through line management, and most are selected by the Laboratory's Executive Committee. (Ten percent of the fund is allocated by Laboratory Associate Directors.) Providing two routes of access to exploratory funds maximizes the likelihood that novel and seminal ideas will be recognized and supported.

A third fund, the Innovative Supercomputing Fund, was established on a trial basis by the ORNL Executive Committee in February 1989. Its purpose is to support innovative computing on the Oak Ridge Cray X-MP on the off hours during nights and weekends. This fund was financed by $100,000 from the Director's R&D Fund. The first call for proposals was made in March 1989.

Table 42. Exploratory R&D funding ($ in millions)

Fiscal year		
1988	1989	1990
5.1	7.0	9.0

The Exploratory Studies Program is administratively part of the ORNL Office of Planning and Management. The position of manager rotates every two years among members of the scientific and technical staff of the Laboratory. Additional description 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, 1988, is 4.77 times the Seed Money investment.

Site and Facilities

Laboratory Description

The Oak Ridge National Laboratory 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 ever-changing description and set of programs that result from the nature of developmental research and evolving national energy priorities requires a high-degree of flexibility in the utilization of the Laboratory's facilities.

Currently the Laboratory occupies approximately 2.6 million square feet of building space at the main Bethel Valley site and the Melton Valley site to the south. In addition, over 1 million square feet of building space at the Oak Ridge Y-12 Plant is allocated to the Laboratory, and approximately 200,000 square feet of space is occupied by ORNL personnel at the Oak Ridge Gaseous Diffusion Plant (ORGDP).

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 ORGDP, 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 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 64 through 69 illustrate the current

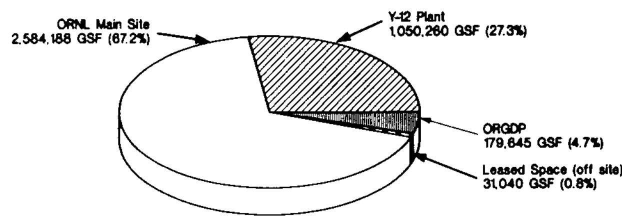


Fig. 64. Laboratory space distribution—location and building area in gross square feet (GSF).

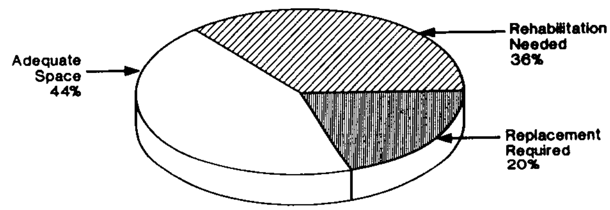


Fig. 65. Condition of Laboratory space by percentage.

distribution, use, age, condition, and size of ORNL buildings. Table 43 lists estimated facility replacement values. The replacement estimates are based on currently active functions and do not include replacement of obsolete facilities nor do they include 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

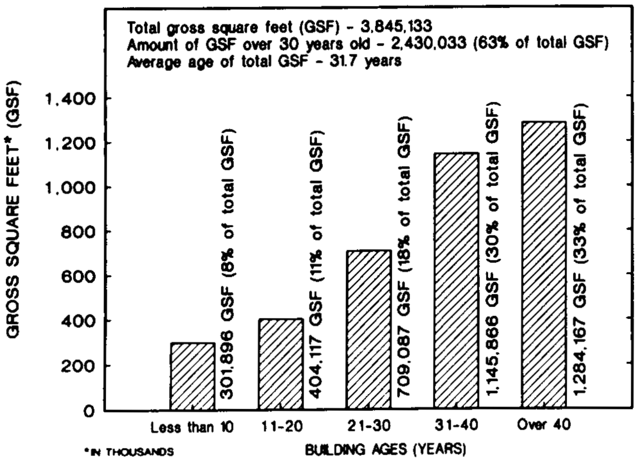


Fig. 66. Gross square footage of Laboratory buildings—categorized by age.

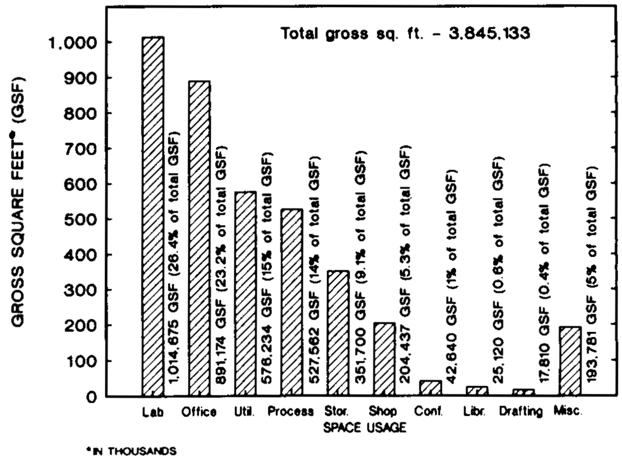


Fig. 68. Use of Laboratory space.

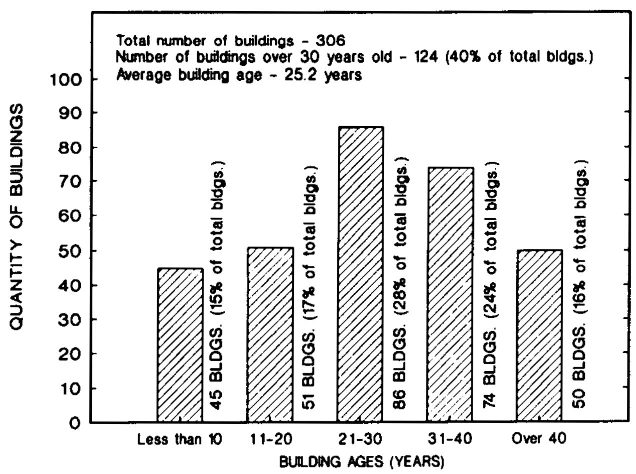


Fig. 67. Distribution of Laboratory buildings by age.

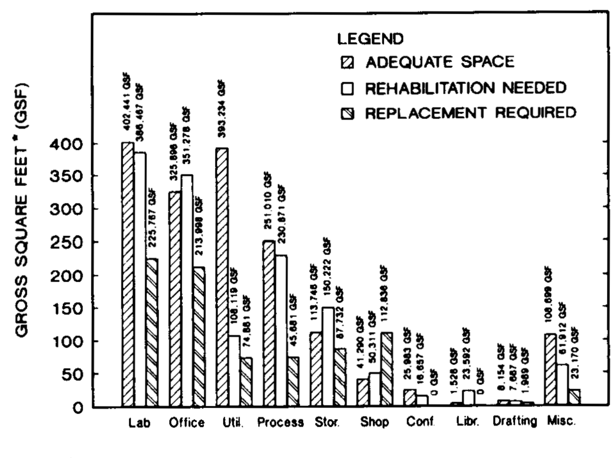


Fig. 69. Condition of Laboratory space—categorized by use.

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.

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

Table 43. Estimated facilities replacement value

Facilities type	Replacement cost range[a] Lower	Replacement cost range[a] 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 facilties	30	50
Subtotal FP 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-1989 dollars.

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.

A summary of the Laboratory's strategic views on overall technical directions indicates that five themes will dominate its programs:

- energy research and development activities;
- global environmental effects;
- environment, safety, and health concerns;
- increased competitiveness; and
- increased outside interactions and technology transfer activities.

As part of ORNL's emphasis on energy and environmental research, several major facility projects are required:

- an Advanced Neutron Source (ANS) for materials science research and isotope production;
- a Heavy Ion Storage Ring for Atomic Physics (HISTRAP) research;
- an Advanced Control Test Operation (ACTO) laboratory to test advanced control concepts for nuclear power reactors; and
- a Life Sciences Complex to establish an efficient, consolidated research center for life sciences programs.

Other major programmatic facilities are required to support continued operations of important isotope production and environmental protection activities. These include

- an Isotopes Processing Complex to modernize and consolidate production facilities and

- a Waste Handling and Packaging Plant for radioactive waste solidification and packaging for shipment to site.

The Laboratory has placed high priority on providing a first-class computing capability to support its research programs. A concept is being developed to establish a consolidated center for ORNL's mainframe computers in a secure basement of a proposed new general-purpose office building. In addition to providing a badly needed facility suitable for supercomputers with appropriate security measures, the new space for the computers will free up a large amount of space in central research buildings to alleviate severely crowded office conditions.

In support of collaborative research with universities and technology transfer goals involving wide-ranging materials science activities, an important new facility is proposed to encourage joint research between ORNL, the Southeastern Universities Research Association, and the Oak Ridge Associated Universities. This Advanced Research Center for Materials Science and Engineering would closely couple university talents with existing ORNL capabilities to offer exceptional strength in DOE research programs and simultaneously support educational programs at southeastern universities.

While ORNL's site and facilities planning is being structured to accommodate these new facilities, planning is also focusing on revitalization of existing buildings and supporting infrastructure. In total, ORNL's planning for capital improvements is directed toward housing at least a 50% increase in the resident research staff by the year 2004.

Two recent management initiatives have been undertaken at ORNL to produce more effective site and facilities plans. First, a new Capital Assets Planning Group has been created and consolidated with institutional planning activities within the Laboratory's Office of Planning and Management. The Office of Planning and Management reports directly to the Laboratory Director to ensure that high priority is given to these integrated planning tasks. A comprehensive study of the present condition of ORNL facilities, combined with future facilities needs, has also been initiated to establish a more complete view of the total facility needs of the Laboratory.

Concurrent with these ORNL capital assets planning initiatives, DOE must provide the necessary funding support in both programmatic and general-purpose facility construction. This combination of thorough site development planning and strong funding will help ensure the establishment of a high-quality research environment at ORNL.

Facilities Resource Requirements

The Laboratory's site and facilities planning staff are in the early stages of preparing a comprehensive ORNL Site Development Plan; a result of this planning effort will be a complete list of construction needs for the Laboratory. An initial list of major construction projects is presented in Table 44. Although these construction activities are below the anticipated total requirements, they provide a major step in ORNL's site and facilities modernization efforts.

Computing and Telecommunications Requirements

Accomplishments in FY 1989

During FY 1989, the ORNL Strategic Plan for Computing was completed and accepted by the Laboratory Executive Committee. This plan outlines, in a broad sense, the directions and priorities that ORNL management believes are important for computing at the Laboratory. The result of a cooperative development among

Table 44. Major construction projects[a]
($ in millions)

	Fiscal year								Total estimated cost
	Funded construction		Budgeted construction		Proposed construction				
	1988	1989	1990	1991	1992	1993	1994	1995	
Program line-item projects[b]									
Heavy Ion Storage Ring for Atomic Physics					7.8	6.5	4.2		18.5
Molecular Genetics Laboratory					1.5	10.8			12.3
Upgrade Mammalian Genetics Facility, air supply					0.5	3.2			3.7
Advanced Neutron Source				39.4	40.7	32.0	TBD[c]	TBD	TBD
Isotopes Area LLW-CAT System Upgrade[d]					7.0	16.1	16.0	3.4	42.5
Waste Handling and Packaging Plant						32.0	60.0	103.0	245.0
Dry Cask Storage							3.5	13.0	26.5
Isotope Processing Complex								12.0	~500.0
Structural Analysis Laboratory						2.0	8.0		10.0
Environmental compliance projects									
Bethel Valley LLW-CAT System Upgrade	4.8	11.78	10.5	7.9					35.0
Melton Valley LLW-CAT System Upgrade					4.0	9.6	9.3	2.1	25.0
Decontamination Facility							5.0	14.0	21.0
Waste Characterization and Certification Faciliy						2.0	4.0	2.0	8.0
Multiprogram general-purpose facilities									
Upgrade Steam Distribution, east end	5.5								6.8
Piping System Restoration, ORNL at Y-12	2.5	0.6							3.8
Building Piping System Upgrade, ORNL at Y-12	0.52	1.33							1.85
Upgrade Fire Protection, ORNL at Y-12	0.77	0.74							1.75
Road Safety Improvements		1.65	0.87						2.52
Measurement and Controls Support Facility			1.1	3.1	0.23				4.43
Electrical System Upgrade			0.855	1.455					2.3
Fire Protection Upgrade			1.34	1.36	0.6				3.3
Central Research and Support Building					7.3	1.3			8.6
Health Physics Instruments Upgrade[d]					4.0	7.0	5.0		16.0

Table 44 (continued)

	Fiscal year								Total estimated cost
	Funded construction		Budgeted construction		Proposed construction				
	1988	1989	1990	1991	1992	1993	1994	1995	
Upgrade Steam Distribution System, west end					1.1	5.15	0.75		7.0
Maintenance Support and Decontamination Laundry Facility					1.0	10.3			11.3
Asbestos Abatement and Research Facility Restoration							1.5	5.0	15.0
ALARA Program Support Facility							1.5	5.0	11.0
Electrical System Upgrade, ORNL at Y-12							1.2	2.5	5.0
Building Cooling System Upgrade								1.5	7.0

[a]Construction data as of October 27, 1989.
[b]Does not include accelerator and reactor improvements and modifications projects.
[c]To be determined.
[d]Funding schedule under discussion.

Laboratory management, the scientific and administrative users groups, and the Computing and Telecommunications Division (C&TD), the plan sets several important new goals and priorities for the future. The accomplishment of these goals will require the development of implementation plans, identification of funding sources, and a shifting of priorities with users and providers of services. In addition, the Energy Systems' Scientific and Technical Workstation Acquisition project, designed to provided a mechanism to allow simplified acquisition of standardized workstations, issued a Request for Proposals and is in the process of evaluating the responses. The agreements with the selected vendors should be completed early in FY 1990, allowing purchases of extremely powerful desktop computing and visualization devices as conveniently as present personal computers (PCs). Because of the availability of workstations through such an agreement and the confusion in the present marketplace over the follow-on to present PCs, acquisitions of PCs is not continuing at the pace of the past years.

The Executive Committee approved funding during FY 1989 to provide 24 pairs of multi-mode fiber optics data communications and 6 pairs of single-mode fiber optics to connect the 4500-N and 4500-S computer rooms and the 6010 building. These improvements are part of a multiyear plan to provide the same connections to buildings 1505, 2506, 3500, and 3025 during FY 1990. Initially, active devices will be installed to provide Ethernet speeds of 10 Mbits/s over this network to connect the majority of the existing computer centers with fiber optics. These devices will be upgraded to FDDI (100 Mbits/s) as new technology makes the replacements more cost-effective. These data connections will be integrated with the Oak Ridge Operations Integrated Communications Network during FY 1992 as it begins to provide PBX and data communications services using fiber optics between the plant sites.

An agreement was made between ORNL management and C&TD to provide a tera-bit massive file system that would be available as a network file server in the near future. This system is expected to be comprised of a robot-operated tape cartridge "silo," providing automatic storage management with all user data appearing to reside on disk, while actually being moved to and from cartridge storage as necessary to meet changing requirements.

During FY 1989, C&TD began the process of converting the operating system for the Cray X-MP located at ORGDP from CTSS to UNICOS. CTSS was a time-sharing system developed at the Lawrence Livermore National Laboratory (LLNL) and is currently in use at the National Magnetic Fusion Energy Computing Center at Livermore. One of the new directions specified in the ORNL Strategic Plan for Computing was that scientific computing would move toward more standardized operating systems and network protocols, such as those dictated in two new Federal Information Systems Standards, FIPS 146 and 151, which address POSIX and GOSIP compliance. While the CTSS operating may become POSIX compliant in the near future, UNICOS, offering a POSIX-compliant UNIX operating system on the Cray, had become the operating system of choice for most Cray users, including the users of the newer Y-MP and the Cray 2 and 3. Because the scientific workstations will be using TCP/IP- (accepted by GOSIP as an interim standard until OSI is completely available) and POSIX-compliant operating systems (which are expected to mostly be UNIX), the choice of UNICOS for the Cray will allow easier development of distributed computing applications and more cost-effective use of central resources. Users will develop and test subsets of applications on local workstations, but they will then do production runs on the central Cray without requiring code changes. Using the X-Window (part of the specification for the workstations) will allow the user interfaces to take place on the local workstations, with the heavy computing being done centrally where cost-effective.

It is evident that a lot of progress was made during FY 1989: a Strategic Plan defined direction; operating system and network protocol standards were identified, and conversions are being made to the accepted standards; acquisitions are planned in congruence with those decisions; high-speed networks are being obtained to support such systems; and the items are integrated with long-range plans for communications systems for Energy Systems.

Trends for the Near Term

The continued budget pressures, caused by environmental concerns, reduction of weapons productions, and increased quality and reporting requirements, will produce a shift in areas on which computing dollars are spent. In an effort to control expenditures more, divisions will begin to acquire more local workstations and shift more work from central computers. Growth will occur in several key areas involved with the management of information necessary for dealing with hazardous waste, quality, improved audit tracking, and corporate data. Much of that growth will be on centrally managed computers, but the analysis of the data will continue to move to the desktop. Reductions have already been seen in several areas that were traditionally carried out on mainframes, such as the preparation of presentation materials, project management, and some statistical analyses.

With the continued move to the desktop, management needs to evaluate the training needs of the desktop computer users. While the platforms offer the potential for improved productivity through faster personal turn-around, improved user interfaces, and excellent productivity software, training for job-specific tasks has not been applied to the extent necessary to achieve the maximum potential. Often personnel have had generalized training, but they have not been taught how to use the computer effectively to perform the job-specific tasks that consume the majority of their time. In addition, excellent software products are available to assist in many tasks that are currently being performed in less than optimal fashion on computers. Management should begin to consider computer productivity studies and the establishment of a user effectiveness study center to identify common problems and provide incremental job-specific training. The requirements for additional staff could sometimes be addressed by improving the productivity of the existing staff through better matches of computer hardware, software, and training.

Needs for Near Term

Laboratory Automation

Laboratories have begun to automate many tasks that were once carried out manually and to acquire instruments that can be connected to personal computers and workstations for automatic collection of data. Better tools are becoming available for analyzing data on the desktop computer and for visualizing the results. An area that has only recently begun to be addressed is that of standardized data formats that are machine-independent and self-identifying. While a great deal can be done to provide more standardized user tools for acquiring, analyzing, and visualizing data, the most important need is to develop laboratory standards for storing data in portable and self-identifying forms. These standards would provide a mechanism for sharing data between applications without costly conversions and would make it possible to develop generic collection, analysis, and visualization packages.

Any attempt to provide widespread laboratory automation services will not begin until such standards are developed. Several other laboratories and supercomputing centers have addressed this issue and developed their internal standards and user-oriented routines to provide standardized data services. A review of existing work in these areas needs to be done, and an implementation plan will need to be prepared to develop such standards for laboratory data. Once the standards are developed, user routines for writing, reading, and manipulating such data objects need to be designed and implemented for the common laboratory computing platforms. The use of standards such as X-Windows and POSIX cannot be overemphasized in this effort. Laboratory data is a priceless commodity that must be given high priority for efficient collecting, analyzing, sharing with collaborators, and archiving for future study. The group assigned to develop such a system will also have in their charter the identification and evaluation of existing scientific software for PCs and workstations as well as the development of interfaces between existing software and the proposed standard laboratory data format. If the management of corporate data is important to keep the laboratory functioning smoothly, the management and treatment of its raison d'être should surely receive the same if not better resources.

ORNL Electronic Mail Improvements

The ORNL Strategic Plan for Computing has identified a goal and a strategy for providing electronic mail to each professional staff member. In addition, it has selected as a goal the delivery of that mail to the platform of the individual's choice. An unstated goal is that this be accomplished in as cost-effective manner as possible. Many users would prefer to have a distributed mail system that delivers the mail to the lowest available node in the mail system hierarchy for storage. For UNIX-(POSIX-) based mail systems with Ethernet connections, that level could be the desktop. For others it would be a departmental or project mail node or server that is accessed from the PC after notification of mail availability. The mail system for the Laboratory should be a nonvendor specific system, based upon the standards specified in the strategic plan, and should be completely "seamless"; that is, to the user, the desktop device is all that is seen. There is no need to "log-in" to remote machines, use different operating systems, or learn new interfaces beyond the mail system the user sees on the desktop device. The development of an implementation plan for ORNL Electronic Mail Services is needed that is consistent with the ORNL Strategic Plan for Computing and offers different cost alternatives and impacts.

Workstations

As the scientific and technical workstation agreement is completed, it will be possible for professionals to acquire very powerful computing engines for their desktop devices for the approximate cost of PCs. These workstations will come with a rich suite of software for scientific computing, including FORTRAN and C compilers and libraries, X-Window libraries and development tools, editors, debuggers, source and binary code management tools, and graphics drivers. The range of computing engines and options will make it possible for users to configure a system to meet most requirements and still allow movement of source costs with little or no modifications between platforms, including the STC UNIX Computer and the Cray X-MP. As these systems are delivered, the needs for training and support will increase. Methods to use automatic and distributed applications (including some expert systems) to assist in the management of workstations should be investigated rather than moving to a manpower intensive support effort.

Scientific Visualization

In the area of scientific visualization, the Laboratory lags most perceptively behind its competition. Researchers in fusion energy report that they have requirements to analyze up to 500 files of about 3 Mbytes of information each for a given set of parameters. The lack of good tools to manage this volume of information and to easily apply a suite of visualization programs to a standardized data form causes a tremendous loss of productivity—specialized programs have to be developed to review the data, to decide what should be revised or refined for final publication, and to try to understand the nature of the processes being investigated. Many of the other national laboratories and computer centers have established visualization centers, resulting in an increase in the quantity and quality of publications and visual material that attracts both public and funding sponsor interest. In addition, the use of many of the visualization tools has resulted in a more rapid increase of new knowledge by using the computer as a visual interactive laboratory instrument to study the complexities of multiparameter nonlinear phenomena.

Parallel Processing

The development of higher energy accelerators, more complex geometry fusion devices, and the keen interest in global warming has created problems for the Laboratory that will require computational power beyond that achievable using scalar or vector computers. Quantum effects, finite electron drift velocities, and statistical fluctuations place physical limits on circuit elements that limit the rate at which a single stream of information can be processed in a computer. In order to overcome these limitations, computer architectures have been developed to allow multiple computational units to operate in parallel. This use of n parallel computers to work on the problem can potentially speed up the processing of the data by a factor of n. While the potential is almost never achieved because of the overhead of communicating intermediate steps between processors, factors of 1000 gain in speed have been achieved using 1024 processors.

In one area, that of relativistic heavy-ion collisions, there is a need for accurate computations of lepton-antilepton pair production for two heavy nuclei colliding at ultrarelativistic velocities. Even using several simplifying assumptions, the theoretical reduction results in coupled partial differential equations for $4N^3$ complex quantities on an N^3 lattice, where N is between 75 and 200. The problem can be cast in a matrix form, which is an ideal form for solution using parallel computers. A Cray 2 computer has been used to perform benchmarks for portions of the code. These suggest that a computer with a capability of about 10^3 to 10^4 megaflops (million floating point operations per second) and a correspondingly large memory is required for a solution. This same capability is required for several problems of interest to Laboratory personnel (e.g., global warming). It is becoming possible to obtain such computers, often called massively parallel computers, for amounts that are not astronomical. The Laboratory needs such instruments if it is to remain competitive in a world in which the ability to compute is synonymous with survival.

Table A.1. Laboratory funding summary

[$ in millions[a]—budget authorization (BA)]

	Fiscal year							
	1988	1989	1990	1991	1992	1993	1994	1995
DOE	307.5	337.4	405.4	425.4	507.0	518.4	491.7	449.3
Work for Others[b]	93.6	82.0	94.8	105.4	102.8	104.8	104.8	104.8
Total operating	401.1	419.4	500.2	530.8	609.8	623.2	596.5	554.1
Capital equipment	17.3	14.5	21.4	22.5	21.6	21.6	21.2	21.2
Program construction[c] Funded/budgeted	4.8	12.5	10.5	47.3				
General-Purpose Facilities Funded/budgeted	9.3	4.3	4.2	5.9				
General Plant Projects (AT, GF, KG)	9.7	11.9	10.5	10.5	10.5	10.5	10.5	10.5
General Purpose Equipment (AT, KG)	4.2	3.4	7.1	9.4	10.3	10.3	10.3	10.3
Total Laboratory[d]	446.4	466.0	553.9	626.4	652.2	665.6	638.5	596.1
Proposed construction								
Program			3.3	11.3	71.0	115.3	111.1[e]	149.5[e]
General-Purpose Facilities					14.2	23.8	10.0	14.0
Total projected funding	446.4	466.0	557.2	637.7	737.4	804.7	759.6[e]	759.6[e]

[a]4.5% escalation from 1989–1990 and 1990–1991. 1991–1995 = constant 1991 dollars.

[b]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 1989, about $17.7 million of ORNL-managed WFO was reported through the other two financial plans and is not included in the above table; $8.5 million of this $17.7 million is part of the Applied Technology Division's $26.6 million (1989) budget, noted in footnote *d*.

[c]Includes environmental compliance projects (KG02) and accelerator and reactor improvements and modifications projects.

[d]Does not include Applied Technology Division, with a budget of ~$20.7 million in 1988, ~$26.6 million in 1989, ~$28.3 million in 1990, and ~$29.5 million in 1991. Approximately 53% of ATD's 1989 budget came from non-DOE sponsors.

[e]Does not include ANS construction costs (TBD).

Table A.2. Laboratory personnel summary

	Fiscal year							
	1988	1989	1990	1991	1992	1993	1994	1995
DOE	1416	1448	1677	1715	1688	1668	1657	1641
Work for Others[a]	374	344	396	403	407	419	416	416
Isotopes production[b]	52	58						
Total technical direct	1842	1850	2073	2118	2095	2087	2073	2057
Other direct	215	242	270	270	264	252	246	243
Total direct personnel	2057	2092	2343	2388	2359	2339	2319	2300
Indirect personnel	2534	2599	2550	2550	2550	2550	2550	2550
Total Laboratory	4591	4691	4893	4938	4909	4889	4869	4850

[a]Includes Nuclear Regulatory Commission.

[b]Beginning in FY 1990, the Isotope Production and Distribution Program is funded via a revolving fund through Program ST.

Table A.3. Funding by assistant secretarial level office

($ in millions)

	FY 1988		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Office of Energy Research																
Total operating	158.8	159.1	161.9	165.0	169.8	170.6	177.3	176.5	177.0	176.2	176.9	176.2	178.0	177.2	175.3	174.6
Capital equipment	15.8		13.2		18.7		22.2		23.7		23.7		23.5		23.5	
Funded/budgeted construction	21.3		25.9		22.7		61.2		8.0		8.0		8.0		8.0	
Total	195.9		201.0		211.2		260.7		208.7		208.6		209.5		206.8	
Assistant Secretary for Nuclear Energy																
Total operating	34.2	36.8	35.9	33.6	66.7	66.3	71.0	70.7	70.8	70.1	68.1	67.6	66.3	65.8	66.2	65.5
Capital equipment	2.3		2.0		3.9		3.3		3.2		3.4		3.5		3.6	
Total	36.5		37.9		70.6		74.3		74.0		71.5		69.8		69.8	
Office of Civilian Radioactive Waste Management																
Total operating	9.2	9.6	10.3	10.6	11.5	10.6	12.1	12.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Capital equipment	*b*		0		0.3		0.3		0.1		0.1		0.1		0.1	
Total	9.2		10.3		11.8		12.4		13.2		13.2		13.2		13.2	
Assistant Secretary for Defense Programs																
Total operating	30.7	33.3	36.8	38.8	72.5	72.4	82.5	82.7	165.8	165.5	184.9	184.6	159.2	158.6	119.2	118.1
Capital equipment	1.7		1.3		2.6		2.9		2.8		2.9		2.8		2.7	
Funded/budgeted construction	2.5		2.8		2.5		2.5		2.5		2.5		2.5		2.5	
Total	34.9		40.9		77.6		87.9		171.1		190.3		164.5		124.4	
Assistant Secretary for Conservation and Renewable Energy																
Total operating	43.8	42.9	45.8	44.9	51.2	51.9	52.9	57.8	50.4	53.4	45.4	45.4	45.0	45.4	45.4	45.4
Capital equipment	0.7		1.0		2.6		2.9		1.8		1.5		1.3		1.3	
Total	44.5		46.8		53.8		55.8		52.2		46.9		46.3		46.7	
Assistant Secretary for Fossil Energy																
Total operating	6.8	7.5	7.2	8.1	6.9	8.0	7.4	8.0	7.7	7.7	7.8	7.8	7.9	7.9	7.9	7.9
Assistant Secretary for Environment, Safety, and Health																
Total operating	8.1	8.8	7.9	7.5	7.0	7.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Capital equipment	0.1		*b*		0.1		0.1		0.1		0.1		0.1		0.1	
Total	8.2		7.9		7.1		7.6		7.6		7.6		7.6		7.6	

Table A.3 (continued)

	FY 1988		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Energy Information Administration																
Total operating	1.1	1.7	1.6	1.4	1.5	1.4	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Assistant Secretary for Management and Administration																
Total operating	0.4	0.3	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Office of Policy, Planning, and Analysis																
Total operating	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Federal Energy Regulatory Commission																
Total operating	0.1	1.4	0	0.1	0	*b*	0	0	0	0	0	0	0	0	0	0
Assistant Secretary for International Affairs and Energy Emergencies																
Total operating	0	*b*	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal DOE Programs																
Total operating	293.4	301.6	308.1	310.4	387.6	388.7	413.1	417.7	494.7	495.9	506.1	504.6	479.4	477.9	437.0	434.5
Capital equipment	20.6		17.5		28.2		31.7		31.7		31.7		31.3		31.3	
Funded/budgeted construction	23.8		28.7		25.2		63.7		10.5		10.5		10.5		10.5	
Total	337.8		354.3		441.0		508.5		536.9		548.3		521.2		478.8	
DOE Contractors and Operations Offices																
Total operating	14.1	14.9	29.3	27.7	17.8	17.8	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3
Capital equipment	0.3		0.4		0.3		0.2		0.2		0.2		0.2		0.2	
Total	14.4		29.7		18.1		12.5		12.5		12.5		12.5		12.5	
Total DOE Programs																
Total operating	307.5	316.5	337.4	338.1	405.4	406.5	425.4	430.0	507.0	508.2	518.4	516.9	491.7	490.2	449.3	446.8
Capital equipment	20.9		17.9		28.5		31.9		31.9		31.9		31.5		31.5	
Funded/budgeted construction	23.8		28.7		25.2		63.7		10.5		10.5		10.5		10.5	
Total DOE Programs	352.2		384.0		459.1		521.0		549.4		560.8		533.7		491.3	
Nuclear Regulatory Commission																
Total operating	12.8	14.3	15.8	14.1	16.1	16.1	16.3	16.3	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5

Table A.3 (continued)

	FY 1988		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Work for Others																
Department of Defense																
Total operating	39.8	52.2	44.8	47.0	55.5	55.8	56.3	57.1	62.4	62.4	64.4	64.4	64.4	64.4	64.4	64.4
Capital equipment	0.4		0		0		0		0		0		0		0	
Total	40.2		44.8		55.5		56.3		62.4		64.4		64.4		64.4	
Other federal agencies																
Total operating	32.5	22.3	15.5	21.5	19.0	25.3	28.7	25.2	19.8	26.3	19.8	25.3	19.8	20.8	19.8	20.8
Capital equipment	0.2		0		0		0		0		0		0		0	
Total	32.7		15.5		19.0		28.7		19.8		19.8		19.8		19.8	
Other Work for Others																
Total operating	8.5	8.1	5.9	5.8	4.2	3.8	4.1	3.8	4.1	3.8	4.1	3.8	4.1	3.8	4.1	3.8
Total Work for Others																
Total operating	93.6	96.9	82.0	88.4	94.8	101.0	105.4	102.4	102.8	109.0	104.8	110.0	104.8	105.5	104.8	105.5
Capital equipment	0.6		0		0		0		0		0		0		0	
Total Work-for-Others programs	94.2		82.0		94.8		105.4		102.8		104.8		104.8		104.8	
Total Laboratory																
Total operating	401.1	413.4	419.4	426.5	500.2	507.5	530.8	532.4	609.8	617.2	623.2	626.9	596.5	595.7	554.1	552.3
Capital equipment	17.3		14.5		21.4		22.5		21.6		21.6		21.2		21.2	
Funded/budgeted construction	4.8		12.5		10.5		47.3		0		0		0		0	
General Purpose Equipment	4.2		3.4		7.1		9.4		10.3		10.3		10.3		10.3	
General Plant Projects	9.7		11.9		10.5		10.5		10.5		10.5		10.5		10.5	
General Purpose Facilities	9.3		4.3		4.2		5.9									
Total	446.4		466.0		553.9		626.4		652.2		665.6		638.5		596.1	
Proposed construction					3.3		11.3		85.2		139.1		121.1[c]		163.5[c]	
Total projected funding	446.4		466.0		557.2		637.7		737.4		804.7		759.6[c]		759.6[c]	

[a]Escalation factors from FY 1989 to FY 1990 and from FY 1990 to FY 1991 are both 4.5%. Figures for FY 1992 through FY 1995 are in constant FY 1991 dollars.
[b]Less than $0.1 million.
[c]Does not include ANS construction costs (TBD).

Table A.4. Personnel by assistant secretarial level office

[Full-time equivalents (FTEs)]

	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	FY 1994	FY 1995
Office of Energy Research								
Technical personnel	807.4	820.0	804.0	804.1	796.4	798.1	800.4	788.7
Other direct personnel	123.3	135.2	116.8	111.8	108.3	102.7	103.0	102.5
Total direct personnel	930.7	955.2	920.8	915.9	904.7	900.8	903.4	891.2
Assistant Secretary for Nuclear Energy								
Technical personnel	164.9	167.8	319.2	331.2	338.3	322.5	313.1	305.1
Other direct personnel	15.7	23.6	59.4	51.7	46.3	39.7	33.5	33.4
Total direct personnel	180.6	191.4	378.6	382.9	384.6	362.2	346.6	338.5
Office of Civilian Radioactive Waste Management								
Technical personnel	29.6	25.4	32.9	34.1	37.4	37.4	37.4	37.4
Other direct personnel	8.3	8.7	12.7	16.4	17.0	17.0	17.0	17.0
Total direct personnel	37.9	34.1	45.6	50.5	54.4	54.4	54.4	54.4
Assistant Secretary for Defense Programs								
Technical personnel	127.2	126.2	216.4	262.4	237.0	237.5	233.5	236.6
Other direct personnel	20.9	27.1	38.2	49.6	52.1	52.6	52.6	50.7
Total direct personnel	148.1	153.3	254.6	312.0	289.1	290.1	286.1	287.3
Assistant Secretary for Conservation and Renewable Energy								
Technical personnel	125.9	135.8	151.7	160.1	156.4	150.4	150.4	150.4
Other direct personnel	3.1	2.3	1.8	1.9	1.9	1.9	1.9	1.9
Total direct personnel	129.0	138.1	153.5	162.0	158.3	152.3	152.3	152.3
Assistant Secretary for Fossil Energy								
Technical personnel	25.2	25.8	29.6	28.4	27.5	27.6	27.7	27.9
Other direct personnel	0.4	0.5	0.2	0.2	0	0	0	0
Total direct personnel	25.6	26.3	29.8	28.6	27.5	27.6	27.7	27.9
Assistant Secretary for Environment, Safety, and Health								
Technical personnel	39.7	27.3	25.0	25.0	25.0	25.0	25.0	25.0
Other direct personnel	3.9	5.2	5.0	5.0	5.0	5.0	5.0	5.0
Total direct personnel	43.6	32.5	30.0	30.0	30.0	30.0	30.0	30.0
Energy Information Administration								
Technical personnel	2.5	2.4	2.7	4.0	4.0	4.0	4.0	4.0
Other direct personnel	0.1	0.2	0.3	1.0	1.0	1.0	1.0	1.0
Total direct personnel	2.6	2.6	3.0	5.0	5.0	5.0	5.0	5.0
Assistant Secretary for Management and Administration								
Technical personnel	0.2	0	0	0	0	0	0	0
Other direct personnel	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table A.4 (continued)

	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	FY 1994	FY 1995
Office of Policy, Planning, and Analysis								
Technical personnel	0.4	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0.4	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Federal Energy Regulatory Commission								
Technical personnel	6.7	0.6	0.1	0	0	0	0	0
Other direct personnel	0.7	0	0	0	0	0	0	0
Total direct personnel	7.4	0.6	0.1	0	0	0	0	0
Assistant Secretary for International Affairs and Energy Emergencies								
Technical personnel	0	0	0	0	0	0	0	0
Other direct personnel	0	0	0	0	0	0	0	0
Total direct personnel	0	0	0	0	0	0	0	0
Subtotal DOE Programs								
Technical personnel	1329.7	1332.2	1582.5	1650.2	1622.9	1603.4	1592.4	1576.0
Other direct personnel	176.7	202.9	235.5	238.7	232.7	221.0	215.1	212.6
Total direct personnel	1506.4	1535.1	1818.0	1888.9	1855.6	1824.4	1807.5	1788.6
DOE Contractors and Operations Offices								
Technical personnel	86.2	116.3	94.0	65.0	65.0	65.0	65.0	65.0
Other direct personnel	2.1	3.2	11.0	7.5	7.5	7.5	7.5	7.5
Total direct personnel	88.3	119.5	105.0	72.5	72.5	72.5	72.5	72.5
Total DOE Programs								
Technical personnel	1415.9	1448.5	1676.5	1715.2	1687.9	1668.4	1657.4	1641.0
Other direct personnel	178.8	206.1	246.5	246.2	240.2	228.5	222.6	220.1
Isotope Production	52.0	58.0						
Total direct personnel	1646.7	1712.6	1923.0	1961.4	1928.1	1896.9	1880.0	1861.1
Nuclear Regulatory Commission								
Technical personnel	60.2	53.8	70.8	68.6	69.5	69.5	69.5	69.5
Other direct personnel	8.4	12.3	8.0	7.5	7.7	7.7	7.7	7.7
Total direct personnel	68.6	66.1	78.8	76.1	77.2	77.2	77.2	77.2
Work for Others								
Department of Defense								
Technical personnel	175.0	166.5	206.8	213.9	219.4	229.7	229.7	229.7
Other direct personnel	16.0	16.9	10.0	10.0	10.0	10.0	10.0	10.0
Total direct personnel	191.0	183.4	216.8	223.9	229.4	239.7	239.7	239.7
Other Federal Agencies								
Technical personnel	113.3	100.9	104.1	105.8	104.0	105.0	102.5	102.5
Other direct personnel	8.3	5.4	5.8	5.8	5.8	5.8	5.3	5.3
Total direct personnel	121.6	106.3	109.9	111.6	109.8	110.8	107.8	107.8

Table A.4 (continued)

	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	FY 1994	FY 1995
Other Work for Others								
Technical personnel	25.9	22.5	14.8	14.4	14.4	14.4	14.4	14.4
Other direct personnel	3.3	1.0	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel	29.2	23.5	14.9	14.5	14.5	14.5	14.5	14.5
Total Work for Others								
Technical personnel	374.4	343.7	396.5	402.7	407.3	418.6	416.1	416.1
Other direct personnel	36.0	35.6	23.9	23.4	23.6	23.6	23.1	23.1
Total direct personnel	410.4	379.3	420.4	426.1	430.9	442.2	439.2	439.2
Total Laboratory								
Technical personnel[a]	1842	1850	2073	2118	2095	2087	2073	2057
Other direct personnel	215	242	270	270	264	252	246	243
Total direct personnel	2057	2092	2343	2388	2359	2339	2319	2300
Total indirect personnel	2534	2599	2550	2550	2550	2550	2550	2550
Total Laboratory personnel	4591	4691	4893	4938	4909	4889	4869	4850

[a]Includes Isotopes Production.

Table A.5. Resources by program

($ in millions)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Office of Energy Research																
AT—Magnetic Fusion[b]																
Total operating	41.7	41.3	39.7	38.6	38.4	38.4	40.8	40.8	40.2	40.2	40.2	40.2	40.2	40.2	40.2	40.2
Capital equipment	3.7		1.9		1.9		2.0		2.0		2.0		2.0		2.0	
Total program	45.4		41.6		40.3		42.8		42.2		42.2		42.2		42.2	
Technical personnel	135.3		124.9		114.7		113.1		112.1		112.1		112.1		112.1	
Other direct personnel	84.3		80.8		71.9		78.1		73.1		73.1		73.1		73.1	
Total direct personnel	219.6		205.7		186.6		191.2		185.2		185.2		185.2		185.2	
AT—Laboratory GPP and GPE Funding																
Total operating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capital equipment	3.8		3.1		6.7		9.0		9.9		9.9		9.9		9.9	
Construction	7.2		6.6		7.0		7.0		7.0		7.0		7.0		7.0	
Total program	11.0		9.7		13.7		16.0		16.9		16.9		16.9		16.9	
Proposed construction	0		0		0		0		0		0		0		0	
Technical personnel	0		0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0		0	
KA—High Energy Physics																
Total operating	0.5	0.4	0.8	0.8	1.4	1.4	1.3	1.3	1.5	1.5	1.6	1.6	1.8	1.8	2.0	2.0
Capital equipment	0		c		0.1		0.1		1.0		1.0		1.2		1.0	
Total program	0.5		0.8		1.5		1.4		2.5		2.6		3.0		3.0	
Technical personnel	2.0		3.6		8.6		7.6		8.4		9.2		10.1		11.1	
Other direct personnel	0.8		0.5		1.4		1.4		1.6		1.8		1.9		2.1	
Total direct personnel	2.8		4.1		10.0		9.0		10.0		11.0		12.0		13.2	
KB—Nuclear Physics																
Total operating	13.6	13.5	13.7	14.4	14.8	14.7	15.3	15.1	15.9	15.7	16.4	16.2	16.4	16.2	16.4	16.2
Capital equipment	1.0		1.1		1.4		1.4		1.6		1.6		1.6		1.6	
Total program	14.6		14.8		16.2		16.7		17.5		18.0		18.0		18.0	
Proposed construction	0		0		2.0		8.0		7.0		0		0		0	
Technical personnel	86.3		88.8		85.5		85.8		89.4		92.2		92.2		92.2	
Other direct personnel	1.5		1.0		1.5		1.5		1.5		1.5		1.5		1.5	
Total direct personnel	87.8		89.8		87.0		87.3		90.9		93.7		93.7		93.7	

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
KC—Basic Energy Sciences																
Total operating	65.3	66.0	71.5	72.8	78.1	78.7	77.9	77.3	77.2	76.6	75.9	75.4	76.0	75.4	75.9	75.4
Capital equipment	5.7		5.6		7.0		7.5		7.0		7.0		6.6		6.8	
Construction	0		0.7		0		39.4		0		0		0		0	
Total program	71.0		77.8		85.1		124.8		84.2		82.9		82.6		82.7	
Proposed construction	0		0		1.3		3.3		51.0		41.6		13.3[d]		0[d]	
Technical personnel	404.0		421.4		415.9		408.0		397.7		395.4		395.4		395.4	
Other direct personnel	19.9		40.6		34.4		22.5		24.1		18.3		18.4		18.4	
Total direct personnel	423.9		462.0		450.3		430.5		421.8		413.7		413.8		413.8	
KD—Energy Research Analyses																
Total operating	1.1	0.4	1.5	1.2	1.1	1.1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Technical personnel	2.3		4.7		3.8		2.5		2.5		2.5		2.5		2.5	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	2.3		4.7		3.8		2.5		2.5		2.5		2.5		2.5	
KE—University Research Support																
Total operating	0.4	0.4	0.8	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Technical personnel	0.3		2.3		4.0		4.0		4.0		4.0		4.0		4.0	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0.3		2.3		4.0		4.0		4.0		4.0		4.0		4.0	
KG—Multiprogram Energy Laboratories Facilities Support																
Total operating	12.9	13.6	8.8	11.4	9.0	9.3	13.1	13.1	13.3	13.3	13.9	13.9	14.7	14.7	11.9	11.9
Capital equipment	0.4		0.3		0.4		0.4		0.4		0.4		0.4		0.4	
Construction	14.1		18.6		15.7		14.8		1.0		1.0		1.0		1.0	
Total program	27.4		27.7		25.1		28.3		14.7		15.3		16.1		13.3	
Proposed construction	0		0		0		0		18.2		35.4		28.3		32.1	
Technical personnel	48.1		51.7		46.5		58.1		57.3		57.7		59.1		46.4	
Other direct personnel	12.8		6.8		2.6		3.3		3.0		3.0		3.1		2.4	
Total direct personnel	60.9		58.5		49.1		61.4		60.3		60.7		62.2		48.8	
KP—Environmental Research and Development																
Total operating	23.3	23.5	25.1	25.0	26.0	26.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
Capital equipment	1.2		1.2		1.2		1.8		1.8		1.8		1.8		1.8	
Total program	24.5		26.3		27.2		28.8		28.8		28.8		28.8		28.8	
Proposed construction	0		0		0		0		2.0		14.0		0		0	
Technical personnel	129.1		122.6		125.0		125.0		125.0		125.0		125.0		125.0	
Other direct personnel	4.0		5.5		5.0		5.0		5.0		5.0		5.0		5.0	
Total direct personnel	133.1		128.1		130.0		130.0		130.0		130.0		130.0		130.0	

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Office of Energy Research																
Total operating	158.8	159.1	161.9	165.0	169.8	170.6	177.3	176.5	177.0	176.2	176.9	176.2	178.0	177.2	175.3	174.6
Capital equipment	15.8		13.2		18.7		22.2		23.7		23.7		23.5		23.5	
Construction	21.3		25.9		22.7		61.2		8.0		8.0		8.0		8.0	
Total	195.9		201.0		211.2		260.7		208.7		208.6		209.5		206.8	
Proposed construction	0		0		3.3		11.3		78.2		91.0		41.6[d]		32.1[d]	
Technical personnel		807.4		820.0		804.0		804.1		796.4		798.1		800.4		788.7
Other direct personnel		123.3		135.2		116.8		111.8		108.3		102.7		103.0		102.5
Total direct personnel		930.7		955.2		920.8		915.9		904.7		900.8		903.4		891.2
Assistant Secretary for Nuclear Energy																
AF—Nuclear Energy Research Development																
Total operating	26.7	29.5	30.5	28.3	40.1	39.7	44.8	44.5	47.4	46.7	45.1	44.6	43.9	43.4	43.8	43.1
Capital equipment	2.2		1.9		3.0		2.4		2.3		2.4		2.5		2.6	
Total program	28.9		32.4		43.1		47.2		49.7		47.5		46.4		46.4	
Technical personnel		129.1		142.5		182.2		194.2		202.9		188.3		177.0		169.0
Other direct personnel		15.6		23.2		18.6		20.6		20.9		14.3		13.1		13.0
Total direct personnel		144.7		165.7		200.8		214.8		223.8		202.6		190.1		182.0
AH—Remedial Action and Waste Technology																
Total operating	7.3	6.9	4.9	4.9	3.2	3.2	4.3	4.3	1.7	1.7	1.4	1.4	0.8	0.8	0.8	0.8
Capital equipment	0.1		0.1		*c*		*c*		*c*		*c*		*c*		*c*	
Total program	7.4		5.0		3.2		4.3		1.7		1.4		0.8		0.8	
Technical personnel		34.2		23.0		14.0		14.0		7.4		6.2		3.1		3.1
Other direct personnel		0.1		0.4		0.8		1.1		0.4		0.4		0.4		0.4
Total direct personnel		34.3		23.4		14.8		15.1		7.8		6.6		3.5		3.5
AJ—Naval Reactors																
Total operating	0	0	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*	*c*
Technical personnel		0		0.3		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		0.3		0.4		0.4		0.4		0.4		0.4		0.4
CD—Uranium Enrichment																
Total operating	0.2	0.4	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Technical personnel		1.6		2.0		2.6		2.6		2.6		2.6		2.6		2.6
Other direct personnel		0		0		0		0		0		0		0		0
Total direct personnel		1.6		2.0		2.6		2.6		2.6		2.6		2.6		2.6

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
ST—Isotope Production and Distribution Program[e]																
Total operating					22.9	22.9	21.4	21.4	21.2	21.2	21.0	21.0	21.0	21.0	21.0	21.0
Capital equipment					0.9		0.9		0.9		1.0		1.0		1.0	
Total program					23.8		22.3		22.1		22.0		22.0		22.0	
Proposed construction					0		0		7.0		16.1		16.0		15.4	
Technical personnel					120.0		120.0		125.0		125.0		130.0		130.0	
Other direct personnel					40.0		30.0		25.0		25.0		20.0		20.0	
Total direct personnel					160.0		150.0		150.0		150.0		150.0		150.0	
Total Assistant Secretary for Nuclear Energy																
Total operating	34.2	36.8	35.9	33.6	66.7	66.3	71.0	70.7	70.8	70.1	68.1	67.6	66.3	65.8	66.2	65.5
Capital equipment	2.3		2.0		3.9		3.3		3.2		3.4		3.5		3.6	
Total	36.5		37.9		70.6		74.3		74.0		71.5		69.8		69.8	
Proposed construction	0		0		0		0		7.0		16.1		16.0		15.4	
Technical personnel	164.9		167.8		319.2		331.2		338.3		322.5		313.1		305.1	
Other direct personnel	15.7		23.6		59.4		51.7		46.3		39.7		33.5		33.4	
Total direct personnel	180.6		191.4		378.6		382.9		384.6		362.2		346.6		338.5	
Office of Civilian Radioactive Waste Management																
DB—Nuclear Waste Fund																
Total operating	9.1	9.5	10.3	10.6	11.5	10.6	12.1	12.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Capital equipment	*c*		0		0.3		0.3		0.1		0.1		0.1		0.1	
Total program	9.1		10.3		11.8		12.4		13.2		13.2		13.2		13.2	
Technical personnel	29.5		25.4		32.9		34.1		37.4		37.4		37.4		37.4	
Other direct personnel	7.8		8.7		12.7		16.4		17.0		17.0		17.0		17.0	
Total direct personnel	37.3		34.1		45.6		50.5		54.4		54.4		54.4		54.4	
DC—Civilian Radioactive Waste Research and Development																
Total operating	0.1	0.1	0	*c*	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0.1		0		0		0		0		0		0		0	
Other direct personnel	0.5		0		0		0		0		0		0		0	
Total direct personnel	0.6		0		0		0		0		0		0		0	
Total Office of Civilian Radioactive Waste Management																
Total operating	9.2	9.6	10.3	10.6	11.5	10.6	12.1	12.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
Capital equipment	*c*		0		0.3		0.3		0.1		0.1		0.1		0.1	
Total	9.2		10.3		11.8		12.4		13.2		13.2		13.2		13.2	
Technical personnel	29.6		25.4		32.9		34.1		37.4		37.4		37.4		37.4	
Other direct personnel	8.3		8.7		12.7		16.4		17.0		17.0		17.0		17.0	
Total direct personnel	37.9		34.1		45.6		50.5		54.4		54.4		54.4		54.4	

Table A.5 (continued)

Assistant Secretary for Defense Programs

	FY 1988			FY 1989			FY 1990[a]			FY 1991[a]		
	BA		BO	BA		BO	BA		BO	BA		BO
GB—Weapons Activities												
Total operating	1.5		0.3	1.7		2.6	2.1		2.1	0.7		0.7
Technical personnel		1.9			13.2			15.0			5.1	
Other direct personnel		0.5			2.4			0.5			0.5	
Total direct personnel		2.4			15.6			15.5			5.6	
GC—Verification and Control Technology												
Total operating	0.2		0.5	0		0	0		0	0		0
Capital equipment	0.1			0			0			0		
Total program	0.3			0			0			0		
Technical personnel		2.2			0			0			0	
Other direct personnel		0			0			0			0	
Total direct personnel		2.2			0			0			0	
GD—Nuclear Safeguards and Security												
Total operating	0.5		0.6	0.5		0.5	0.5		0.5	0.5		0.5
Capital equipment	0.1			0.2			0.1			0.2		
Total program	0.6			0.7			0.6			0.7		
Technical personnel		4.1			3.8			3.7			3.7	
Other direct personnel		0			0			0			0	
Total direct personnel		4.1			3.8			3.7			3.7	
GE—Materials Production												
Total operating	5.6		5.7	7.5		8.2	20.1		20.1	40.0		40.0
Capital equipment	0.2			0.2			1.0			1.8		
Total program	5.8			7.7			21.1			41.8		
Technical personnel		42.3			40.7			90.9			153.2	
Other direct personnel		1.1			2.6			10.7			18.0	
Total direct personnel		43.4			43.3			101.6			171.2	
GF—Defense Waste and Environmental Restoration												
Total operating	22.9		26.2	27.1		27.5	49.8		49.7	41.3		41.5
Capital equipment	1.3			0.9			1.5			0.9		
Construction	2.5			2.8			2.5			2.5		
Total program	26.7			30.8			53.8			44.7		
Proposed construction	0			0			0			0		
Technical personnel		76.7			68.5			106.8			100.4	
Other direct personnel		19.3			22.1			27.0			31.1	
Total direct personnel		96.0			90.6			133.8			131.5	

	FY 1992[a]			FY 1993[a]			FY 1994[a]			FY 1995[a]		
	BA		BO	BA		BO	BA		BO	BA		BO
GB—Weapons Activities												
Total operating	0.3		0.3	0.3		0.3	0.3		0.3	0.3		0.3
Technical personnel		2.0			2.0			2.0			2.0	
Other direct personnel		0.5			0.5			0.5			0.5	
Total direct personnel		2.5			2.5			2.5			2.5	
GC—Verification and Control Technology												
Total operating	0		0	0		0	0		0	0		0
Capital equipment	0			0			0			0		
Total program	0			0			0			0		
Technical personnel		0			0			0			0	
Other direct personnel		0			0			0			0	
Total direct personnel		0			0			0			0	
GD—Nuclear Safeguards and Security												
Total operating	0.5		0.5	0.6		0.6	0.6		0.6	0.6		0.6
Capital equipment	0.2			0.2			0.2			0.2		
Total program	0.7			0.8			0.8			0.8		
Technical personnel		3.7			3.7			3.7			3.7	
Other direct personnel		0			0			0			0	
Total direct personnel		3.7			3.7			3.7			3.7	
GE—Materials Production												
Total operating	36.5		36.5	36.6		36.6	36.6		36.6	36.6		36.6
Capital equipment	1.5			1.5			1.5			1.5		
Total program	38.0			38.1			38.1			38.1		
Technical personnel		118.7			118.7			118.7			118.7	
Other direct personnel		18.9			18.9			18.9			18.9	
Total direct personnel		137.6			137.6			137.6			137.6	
GF—Defense Waste and Environmental Restoration												
Total operating	128.5		128.2	147.4		147.1	121.7		121.1	81.7		80.6
Capital equipment	1.1			1.2			1.1			1.0		
Construction	2.5			2.5			2.5			2.5		
Total program	132.1			151.1			125.3			85.2		
Proposed construction	0			32.0			63.5			116.0		
Technical personnel		112.6			113.1			109.1			112.2	
Other direct personnel		32.7			33.2			33.2			31.3	
Total direct personnel		145.3			146.3			142.3			143.5	

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Total Assistant Secretary for Defense Programs																
Total operating	30.7	33.3	36.8	38.8	72.5	72.4	82.5	82.7	165.8	165.5	184.9	184.6	159.2	158.6	119.2	118.1
Capital equipment	1.7		1.3		2.6		2.9		2.8		2.9		2.8		2.7	
Construction	2.5		2.8		2.5		2.5		2.5		2.5		2.5		2.5	
Total	34.9		40.9		77.6		87.9		171.1		190.3		164.5		124.4	
Proposed construction	0		0		0		0		0		32.0		63.5		116.0	
Technical personnel		127.2		126.2		216.4		262.4		237.0		237.5		233.5		236.6
Other direct personnel		20.9		27.1		38.2		49.6		52.1		52.6		52.6		50.7
Total direct personnel		148.1		153.3		254.6		312.0		289.1		290.1		286.1		287.3
Assistant Secretary for Conservation and Renewable Energy																
AK—Electric Energy Systems																
Total operating	3.1	4.1	4.6	4.6	6.8	6.3	9.2	9.2	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
Capital equipment	0		0		0.2		0.3		0.3		0.3		0.3		0.3	
Total program	3.1		4.6		7.0		9.5		9.6		9.6		9.6		9.6	
Technical personnel		10.9		15.2		20.9		26.7		26.7		26.7		26.7		26.7
Other direct personnel		0.4		0		0		0		0		0		0		0
Total direct personnel		11.3		15.2		20.9		26.7		26.7		26.7		26.7		26.7
AL—Energy Storage Systems																
Total operating	0.9	0.6	1.0	1.0	0.8	0.9	0.8	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Technical personnel		2.0		2.9		1.9		1.9		1.9		1.9		1.9		1.9
Other direct personnel		0		0.1		0		0		0		0		0		0
Total direct personnel		2.0		3.0		1.9		1.9		1.9		1.9		1.9		1.9
AM—Geothermal Energy																
Total operating	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Technical personnel		0.7		0.5		0.6		0.6		0.6		0.6		0.6		0.6
Other direct personnel		0		0		0		0		0		0		0		0
Total direct personnel		0.7		0.5		0.6		0.6		0.6		0.6		0.6		0.6
CE—Hydropower																
Total operating	0	c	c	c	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Technical personnel		0		0.1		1.5		1.5		1.5		1.5		1.5		1.5
Other direct personnel		0.2		0		0		0		0		0		0		0
Total direct personnel		0.2		0.1		1.5		1.5		1.5		1.5		1.5		1.5
EB—Solar Energy																
Total operating	3.3	5.4	2.8	4.4	4.0	3.9	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Capital equipment	0		0.1		0.1		0.1		0.1		0.1		0.1		0.1	
Total program	3.3		2.9		4.1		4.2		4.2		4.2		4.2		4.2	
Technical personnel		10.8		8.3		10.5		10.8		10.8		10.8		10.8		10.8
Other direct personnel		0		0		0.1		0.1		0.1		0.1		0.1		0.1
Total direct personnel		10.8		8.3		10.6		10.9		10.9		10.9		10.9		10.9

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
EC—Buildings and Community Systems																
Total operating	10.6	10.1	9.9	9.8	10.7	12.1	11.1	11.9	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6
Capital equipment	0.2		0.3		0.7		0.4		0.4		0.4		0.4		0.4	
Total program	10.8		10.2		11.4		11.5		12.0		12.0		12.0		12.0	
Technical personnel	29.9		33.2		35.5		34.7		34.8		34.8		34.8		34.8	
Other direct personnel	1.8		1.3		0.8		0.7		0.7		0.7		0.7		0.7	
Total direct personnel	31.7		34.5		36.3		35.4		35.5		35.5		35.5		35.5	
ED—Industrial Energy Conservation																
Total operating	2.2	1.7	2.3	2.4	3.2	3.1	2.9	2.7	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Capital equipment	0		0		*c*		*c*		*c*		*c*		*c*		*c*	
Total program	2.2		2.3		3.2		2.9		2.8		2.8		2.8		2.8	
Technical personnel	8.8		10.3		12.5		11.9		12.5		12.5		12.5		12.5	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	8.8		10.3		12.5		11.9		12.5		12.5		12.5		12.5	
EE—Transportation																
Total operating	17.3	14.7	19.6	17.3	20.3	20.2	18.8	23.1	15.8	18.8	10.8	10.8	10.4	10.8	10.8	10.8
Capital equipment	0.2		0.6		1.5		1.9		1.0		0.7		0.5		0.5	
Total program	17.5		20.2		21.8		20.7		16.8		11.5		10.9		11.3	
Technical personnel	40.1		46.5		46.2		47.9		43.5		37.5		37.5		37.5	
Other direct personnel	0.7		0.9		0.6		0.7		0.7		0.7		0.7		0.7	
Total direct personnel	40.8		47.4		46.8		48.6		44.2		38.2		38.2		38.2	
EF—State/Local Programs																
Total operating	0.4	0.3	0.3	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Technical personnel	0.3		1.6		2.0		2.2		2.2		2.2		2.2		2.2	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0.3		1.6		2.0		2.2		2.2		2.2		2.2		2.2	
EG—Multisector																
Total operating	5.9	5.9	5.3	4.9	4.7	4.7	5.1	5.0	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Capital equipment	0.3		*c*		0.1		0.2		0		0		0		0	
Total program	6.2		5.3		4.8		5.3		5.1		5.1		5.1		5.1	
Technical personnel	22.4		17.2		20.1		21.9		21.9		21.9		21.9		21.9	
Other direct personnel	0		0		0.3		0.4		0.4		0.4		0.4		0.4	
Total direct personnel	22.4		17.2		20.4		22.3		22.3		22.3		22.3		22.3	

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Total Assistant Secretary for Conservation and Renewable Energy																
Total operating	43.8	42.9	45.8	44.9	51.2	51.9	52.9	57.8	50.4	53.4	45.4	45.4	45.0	45.4	45.4	45.4
Capital equipment	0.7		1.0		2.6		2.9		1.8		1.5		1.3		1.3	
Total	44.5		46.8		53.8		55.8		52.2		46.9		46.3		46.7	
Technical personnel	125.9		135.8		151.7		160.1		156.4		150.4		150.4		150.4	
Other direct personnel	3.1		2.3		1.8		1.9		1.9		1.9		1.9		1.9	
Total direct personnel	129.0		138.1		153.5		162.0		158.3		152.3		152.3		152.3	
Assistant Secretary for Fossil Energy																
AA—Coal																
Total operating	5.9	6.9	5.8	7.3	5.9	6.7	6.1	6.6	6.4	6.4	6.5	6.5	6.6	6.6	6.6	6.6
Technical personnel	22.0		22.1		21.9		20.6		20.1		20.2		20.3		20.5	
Other direct personnel	0.4		0.5		0.2		0.2		0		0		0		0	
Total direct personnel	22.4		22.6		22.1		20.8		20.1		20.2		20.3		20.5	
AC—Petroleum																
Total operating	0	*c*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0.2		0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0.2		0		0		0		0		0		0		0	
AN—Energy Technology Center Program Direction																
Total operating	0.1	0	0	*c*	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Technical personnel	0		0.1		1.0		0.8		0.5		0.5		0.5		0.5	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0		0.1		1.0		0.8		0.5		0.5		0.5		0.5	
AZ—Innovative Clean Coal Technology																
Total operating	0.5	0.4	1.1	0.5	0.4	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Technical personnel	1.9		2.1		4.4		4.9		4.9		4.9		4.9		4.9	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	1.9		2.1		4.4		4.9		4.9		4.9		4.9		4.9	
SA—Strategic Petroleum Reserve																
Total operating	0.3	0.2	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Technical personnel	1.1		1.5		2.3		2.1		2.0		2.0		2.0		2.0	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	1.1		1.5		2.3		2.1		2.0		2.0		2.0		2.0	

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Total Assistant Secretary for Fossil Energy																
Total operating	6.8	7.5	7.2	8.1	6.9	8.0	7.4	8.0	7.7	7.7	7.8	7.8	7.9	7.9	7.9	7.9
Technical personnel	25.2		25.8		29.6		28.4		27.5		27.6		27.7		27.9	
Other direct personnel	0.4		0.5		0.2		0.2		0		0		0		0	
Total direct personnel	25.6		26.3		29.8		28.6		27.5		27.6		27.7		27.9	
Assistant Secretary for Environment, Safety, and Health																
HA—Environment, Safety, and Health																
Total operating	8.1	8.8	7.9	7.5	7.0	7.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Capital equipment	0.1		*c*		0.1		0.1		0.1		0.1		0.1		0.1	
Total program	8.2		7.9		7.1		7.6		7.6		7.6		7.6		7.6	
Technical personnel	39.7		27.3		25.0		25.0		25.0		25.0		25.0		25.0	
Other direct personnel	3.9		5.2		5.0		5.0		5.0		5.0		5.0		5.0	
Total direct personnel	43.6		32.5		30.0		30.0		30.0		30.0		30.0		30.0	
Total Assistant Secretary for Environment, Safety, and Health																
Total operating	8.1	8.8	7.9	7.5	7.0	7.0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Capital equipment	0.1		*c*		0.1		0.1		0.1		0.1		0.1		0.1	
Total	8.2		7.9		7.1		7.6		7.6		7.6		7.6		7.6	
Technical personnel	39.7		27.3		25.0		25.0		25.0		25.0		25.0		25.0	
Other direct personnel	3.9		5.2		5.0		5.0		5.0		5.0		5.0		5.0	
Total direct personnel	43.6		32.5		30.0		30.0		30.0		30.0		30.0		30.0	
Energy Information Administration																
TA—Energy Information Administration System																
Total operating	1.1	1.7	1.6	1.4	1.5	1.4	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Technical personnel	2.5		2.4		2.7		4.0		4.0		4.0		4.0		4.0	
Other direct personnel	0.1		0.2		0.3		1.0		1.0		1.0		1.0		1.0	
Total direct personnel	2.6		2.6		3.0		5.0		5.0		5.0		5.0		5.0	
Total Energy Information Administration																
Total operating	1.1	1.7	1.6	1.4	1.5	1.4	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Technical personnel	2.5		2.4		2.7		4.0		4.0		4.0		4.0		4.0	
Other direct personnel	0.1		0.2		0.3		1.0		1.0		1.0		1.0		1.0	
Total direct personnel	2.6		2.6		3.0		5.0		5.0		5.0		5.0		5.0	

Table A.5 (continued)

	FY 1988 BA	FY 1988 BO	FY 1989 BA	FY 1989 BO	FY 1990[a] BA	FY 1990[a] BO	FY 1991[a] BA	FY 1991[a] BO	FY 1992[a] BA	FY 1992[a] BO	FY 1993[a] BA	FY 1993[a] BO	FY 1994[a] BA	FY 1994[a] BO	FY 1995[a] BA	FY 1995[a] BO
Assistant Secretary for Management and Administration																
WA—General Administration																
Total operating	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0		0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0		0	
WB—In-House Energy Management																
Total operating	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Technical personnel	0		0		0		0		0		0		0		0	
Other direct personnel	0.3		0.1		1.1		1.1		1.1		1.1		1.1		1.1	
Total direct personnel	0.3		0.1		1.1		1.1		1.1		1.1		1.1		1.1	
WM—Services																
Total operating	0.1	0.1	0	c	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0.2		0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0.2		0		0		0		0		0		0		0	
Total Assistant Secretary for Management and Administration																
Total operating	0.4	0.3	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Technical personnel	0.2		0		0		0		0		0		0		0	
Other direct personnel	0.3		0.1		1.1		1.1		1.1		1.1		1.1		1.1	
Total direct personnel	0.5		0.1		1.1		1.1		1.1		1.1		1.1		1.1	
Office of Policy, Planning, and Analysis																
PE—Policy, Planning, and Analysis																
Total operating	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	0.4		0.9		0.9		0.9		0.9		0.9		0.9		0.9	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0.4		0.9		0.9		0.9		0.9		0.9		0.9		0.9	
Total Office of Policy, Planning, and Analysis																
Total operating	0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	0.4		0.9		0.9		0.9		0.9		0.9		0.9		0.9	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0.4		0.9		0.9		0.9		0.9		0.9		0.9		0.9	

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Federal Energy Regulatory Commission																
VR—Federal Energy Regulatory Commission																
Total operating	0.1	1.4	0	0.1	0	*c*	0	0	0	0	0	0	0	0	0	0
Technical personnel	6.7		0.6		0.1		0		0		0		0		0	
Other direct personnel	0.7		0		0		0		0		0		0		0	
Total direct personnel	7.4		0.6		0.1		0		0		0		0		0	
Total Federal Energy Regulatory Commission																
Total operating	0.1	1.4	0	0.1	0	*c*	0	0	0	0	0	0	0	0	0	0
Technical personnel	6.7		0.6		0.1		0		0		0		0		0	
Other direct personnel	0.7		0		0		0		0		0		0		0	
Total direct personnel	7.4		0.6		0.1		0		0		0		0		0	
Assistant Secretary for International Affairs and Energy Emergencies																
NA—International Affairs																
Total operating	0	*c*	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0		0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0		0	
Total Assistant Secretary for International Affairs and Energy Emergencies																
Total operating	0	*c*	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0		0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0		0	
Subtotal DOE Programs																
Total operating	293.4	301.6	308.1	310.4	387.6	388.7	413.1	417.7	494.7	495.9	506.1	504.6	479.4	477.9	437.0	434.5
Capital equipment	20.6		17.5		28.2		31.7		31.7		31.7		31.3		31.3	
Construction	23.8		28.7		25.2		63.7		10.5		10.5		10.5		10.5	
Total	337.8		354.3		441.0		508.5		536.9		548.3		521.2		478.8	
Proposed construction	0		0		3.3		11.3		85.2		139.1		121.1[d]		163.5[d]	
Technical personnel	1329.7		1332.2		1582.5		1650.2		1622.9		1603.4		1592.4		1576.0	
Other direct personnel	176.7		202.9		235.5		238.7		232.7		221.0		215.1		212.6	
Total direct personnel	1506.4		1535.1		1818.0		1888.9		1855.6		1824.4		1807.5		1788.6	

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
DOE Contractors and Operations Office																
Total operating	14.1	14.9	29.3	27.7	17.8	17.8	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3	12.3
Capital equipment	0.3		0.4		0.3		0.2		0.2		0.2		0.2		0.2	
Total program	14.4		29.7		18.1		12.5		12.5		12.5		12.5		12.5	
Technical personnel	86.2		116.3		94.0		65.0		65.0		65.0		65.0		65.0	
Other direct personnel	2.1		3.2		11.0		7.5		7.5		7.5		7.5		7.5	
Total direct personnel	88.3		119.5		105.0		72.5		72.5		72.5		72.5		72.5	
Total DOE Programs																
Total operating	307.5	316.5	337.4	338.1	405.4	406.5	425.4	430.0	507.0	508.2	518.4	516.9	491.7	490.2	449.3	446.8
Capital equipment	20.9		17.9		28.5		31.9		31.9		31.9		31.5		31.5	
Construction	23.8		28.7		25.2		63.7		10.5		10.5		10.5		10.5	
Total program	352.2		384.0		459.1		521.0		549.4		560.8		533.7		491.3	
Proposed construction	0		0		3.3		11.3		85.2		139.1		121.1[d]		163.5[d]	
Technical personnel	1415.9		1448.5		1676.5		1715.2		1687.9		1668.4		1657.4		1641.0	
Other direct personnel	178.8		206.1		246.5		246.2		240.2		228.5		222.6		220.1	
Isotope production personnel	52.0		58.0													
Total direct personnel	1646.7		1712.6		1923.0		1961.4		1928.1		1896.9		1880.0		1861.1	
Work for Others																
Nuclear Regulatory Commission																
Total operating	12.8	14.3	15.8	14.1	16.1	16.1	16.3	16.3	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
Technical personnel	60.2		53.8		70.8		68.6		69.5		69.5		69.5		69.5	
Other direct personnel	8.4		12.3		8.0		7.5		7.7		7.7		7.7		7.7	
Total direct personnel	68.6		66.1		78.8		76.1		77.2		77.2		77.2		77.2	
Department of Defense—Space and Defense Technologies																
Total operating	23.3	24.1	34.6	29.8	37.1	37.1	39.2	39.2	45.4	45.4	47.4	47.4	47.4	47.4	47.4	47.4
Capital equipment	0.4		0		0		0		0		0		0		0	
Total program	23.7		34.6		37.1		39.2		45.4		47.4		47.4		47.4	
Technical personnel	97.7		114.3		139.9		137.1		143.0		153.3		153.3		153.3	
Other direct personnel	9.6		10.1		10.0		10.0		10.0		10.0		10.0		10.0	
Total direct personnel	107.3		124.4		149.9		147.1		153.0		163.3		163.3		163.3	
Department of Defense—Data Systems																
Total operating	10.8	21.9	5.2	11.2	12.4	12.7	10.1	10.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Technical personnel	46.4		30.0		36.0		29.4		29.0		29.0		29.0		29.0	
Other direct personnel	5.2		2.9		0		0		0		0		0		0	
Total direct personnel	51.6		32.9		36.0		29.4		29.0		29.0		29.0		29.0	

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Department of Defense—Hazardous Waste R&D																
Total operating	5.7	6.2	5.0	6.0	6.0	6.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Technical personnel	30.9		22.2		30.9		47.4		47.4		47.4		47.4		47.4	
Other direct personnel	1.2		3.9		0		0		0		0		0		0	
Total direct personnel	32.1		26.1		30.9		47.4		47.4		47.4		47.4		47.4	
Total Department of Defense																
Total operating	39.8	52.2	44.8	47.0	55.5	55.8	56.3	57.1	62.4	62.4	64.4	64.4	64.4	64.4	64.4	64.4
Capital equipment	0.4		0		0		0		0		0		0		0	
Total program	40.2		44.8		55.5		56.3		62.4		64.4		64.4		64.4	
Technical personnel	175.0		166.5		206.8		213.9		219.4		229.7		229.7		229.7	
Other direct personnel	16.0		16.9		10.0		10.0		10.0		10.0		10.0		10.0	
Total direct personnel	191.0		183.4		216.8		223.9		229.4		239.7		239.7		239.7	
National Aeronautics and Space Administration																
Total operating	2.5	2.6	2.4	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Technical personnel	16.5		15.0		15.0		15.0		15.0		15.0		15.0		15.0	
Other direct personnel	1.5		0.8		0.8		0.8		0.8		0.8		0.8		0.8	
Total direct personnel	18.0		15.8		15.8		15.8		15.8		15.8		15.8		15.8	
Department of Health and Human Services																
Total operating	4.9	5.5	4.6	5.3	5.5	5.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Technical personnel	35.6		28.9		29.5		30.0		30.0		30.0		30.0		30.0	
Other direct personnel	0.3		0.4		0.5		0.5		0.5		0.5		0.5		0.5	
Total direct personnel	35.9		29.3		30.0		30.5		30.5		30.5		30.5		30.5	
Environmental Protection Agency																
Total operating	4.2	4.2	4.3	4.4	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Capital equipment	0.1		0		0		0		0		0		0		0	
Total program	4.3		4.3		4.5		4.5		4.5		4.5		4.5		4.5	
Technical personnel	21.2		23.3		24.0		24.0		24.0		24.0		24.0		24.0	
Other direct personnel	3.2		2.6		2.0		2.0		2.0		2.0		2.0		2.0	
Total direct personnel	24.4		25.9		26.0		26.0		26.0		26.0		26.0		26.0	
National Science Foundation																
Total operating	0.9	1.2	0.5	0.7	0.9	0.9	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Technical personnel	5.9		2.6		4.5		5.5		5.5		5.5		5.5		5.5	
Other direct personnel	0.9		*c*		0.5		0.5		0.5		0.5		0.5		0.5	
Total direct personnel	6.8		2.6		5.0		6.0		6.0		6.0		6.0		6.0	

Table A.5 (continued)

	FY 1988			FY 1989			FY 1990[a]			FY 1991[a]			FY 1992[a]			FY 1993[a]			FY 1994[a]			FY 1995[a]		
	BA		BO	BA		BO	BA		BO	BA		BO	BA		BO	BA		BO	BA		BO	BA		BO
Federal Emergency Management Agency																								
Total operating	1.7		2.2	1.3		2.3	2.3		2.3	2.3		2.3	2.3		2.3	2.3		2.3	2.3		2.3	2.3		2.3
Technical personnel		9.7			9.6			10.0			10.0			10.0			10.0			10.0			10.0	
Other direct personnel		1.0			1.1			1.0			1.0			1.0			1.0			1.0			1.0	
Total direct personnel		10.7			10.7			11.0			11.0			11.0			11.0			11.0			11.0	
Agency for International Development																								
Total operating	2.1		2.5	0.9		2.0	1.7		1.8	1.7		1.7	1.8		1.8	1.8		1.8	1.8		1.8	1.8		1.8
Technical personnel		8.7			4.8			5.6			5.8			6.0			6.0			6.0			6.0	
Other direct personnel		*c*			0			0			0			0			0			0			0	
Total direct personnel		8.7			4.8			5.6			5.8			6.0			6.0			6.0			6.0	
Department of the Treasury																								
Total operating	14.5		1.9	0		2.5	0		6.2	9.0		5.5	0		6.5	0		5.5	0		1.0	0		1.0
Technical personnel		7.1			10.9			10.0			10.0			8.0			9.0			6.5			6.5	
Other direct personnel		0.9			0.4			1.0			1.0			1.0			1.0			0.5			0.5	
Total direct personnel		8.0			11.3			11.0			11.0			9.0			10.0			7.0			7.0	
Other Federal Agencies																								
Total operating	1.7		2.2	1.5		1.8	1.6		1.6	1.6		1.6	1.6		1.6	1.6		1.6	1.6		1.6	1.6		1.6
Capital equipment	0.1			0			0			0			0			0			0			0		
Total program	1.8			1.5			1.6			1.6			1.6			1.6			1.6			1.6		
Technical personnel		8.6			5.8			5.5			5.5			5.5			5.5			5.5			5.5	
Other direct personnel		0.5			0.1			0			0			0			0			0			0	
Total direct personnel		9.1			5.9			5.5			5.5			5.5			5.5			5.5			5.5	
Electric Power Research Institute																								
Total operating	5.7		4.6	3.6		3.8	2.0		2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0		2.0	2.0		2.0
Technical personnel		15.2			11.6			5.0			5.0			5.0			5.0			5.0			5.0	
Other direct personnel		2.3			0.5			0			0			0			0			0			0	
Total direct personnel		17.5			12.1			5.0			5.0			5.0			5.0			5.0			5.0	
Other Nonfederal Agencies																								
Total operating	2.8		3.5	2.3		2.0	2.2		1.8	2.1		1.8	2.1		1.8	2.1		1.8	2.1		1.8	2.1		1.8
Technical personnel		10.7			10.9			9.8			9.4			9.4			9.4			9.4			9.4	
Other direct personnel		1.0			0.5			0.1			0.1			0.1			0.1			0.1			0.1	
Total direct personnel		11.7			11.4			9.9			9.5			9.5			9.5			9.5			9.5	

Table A.5 (continued)

	FY 1988		FY 1989		FY 1990[a]		FY 1991[a]		FY 1992[a]		FY 1993[a]		FY 1994[a]		FY 1995[a]	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Total Work for Others[f]																
Total operating	93.6	96.9	82.0	88.4	94.8	101.0	105.4	102.4	102.8	109.0	104.8	110.0	104.8	105.5	104.8	105.5
Capital equipment	0.6		0		0		0		0		0		0		0	
Total	94.2		82.0		94.8		105.4		102.8		104.8		104.8		104.8	
Technical personnel	374.4		343.7		396.5		402.7		407.3		418.6		416.1		416.1	
Other direct personnel	36.0		35.6		23.9		23.4		23.6		23.6		23.1		23.1	
Total direct personnel	410.4		379.3		420.4		426.1		430.9		442.2		439.2		439.2	
Total Program Resources[g]																
Total operating	401.1	413.4	419.4	426.5	500.2	507.5	530.8	532.4	609.8	617.2	623.2	626.9	596.5	595.7	554.1	552.3
Capital equipment	21.5		17.9		28.5		31.9		31.9		31.9		31.5		31.5	
Construction	23.8		28.7		25.2		63.7		10.5		10.5		10.5		10.5	
Total	446.4		466.0		553.9		626.4		652.2		665.6		638.5		596.1	
Proposed construction	0		0		3.3		11.3		85.2		139.1		121.1[d]		163.5[d]	
Technical personnel	1790		1792		2073		2118		2095		2087		2073		2057	
Other direct personnel	215		242		270		270		264		252		246		243	
Isotope Production	52		58													
Total direct personnel	2057		2092		2343		2388		2359		2339		2319		2300	

[a]Escalation factors from FY 1989 to FY 1990 and from FY 1990 to FY 1991 are both 4.5%. Figures for FY 1992 through FY 1995 are in constant FY 1991 dollars.
[b]Includes CIT funding from Princeton Plasma Physics Laboratory.
[c]Less than $0.1 million or less than 0.1 FTE.
[d]Does not include ANS construction costs (TBD).
[e]Beginning in FY 1990, the Isotope Production and Distribution Program is funded via a revolving fund through Program ST.
[f]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 1989, about $17.7 million of ORNL-managed WFO was reported through the other two financial plans and is not included in the above table; $8.5 million of this $17.7 million is part of the Applied Technology Division's $26.6 million (1989) budget, noted in footnote g.
[g]Does not include Applied Technology Division, with a budget of ~$20.7 million in 1988, ~$26.6 million in 1989, ~$28.3 million in 1990, and ~$29.5 million in 1991. Approximately 53% of ATD's 1989 budget came from non-DOE sponsors.

Acronyms

AA	Affirmative Action
ACTO	Advanced Control Test Operation
AEOD	Office for Analysis and Evaluation of Operational Data
AI	artificial intelligence
AID	Agency for International Development
AIM	Accelerator Improvement and Maintenance
AIRD	Acoustic Instrumentation Research and Development
ALMR	Advanced Liquid Metal Reactor
ANL	Argonne National Laboratory
ANS	Advanced Neutron Source
API	American Petroleum Institute
AR&TD	Advanced Research and Technology Development
ARC	Advanced Research Center
ARIES	Advanced Reactor Innovation and Evaluation Study
ASM	Advanced Structural Materials
ATD	Applied Technology Division
ATF	advanced toroidal facility
ATSDR	Agency for Toxic Substances and Disease Registry
AVLIS	Atomic Vapor Isotope Separation
AVR	Arbeitsgemeinschaft Versuchsreaktor
BA	budget authorization
BES	Basic Energy Sciences
BNL	Brookhaven National Laboratory
BRC	Bioprocessing Research Center
BRF	Bioprocessing Research Facility
BRS	broad-range magnetic spectrograph
BSR	Bulk Shielding Reactor
BTESM	Building Thermal Envelope Systems and Materials
C&TD	Computing and Telecommunications Division
CBCF	carbon-bonded carbon-fiber
CCP	Clean Coal Program
CDIAC	Carbon Dioxide Information Analysis Center
CDIARP	Carbon Dioxide Information Analysis and Research Program
CE	Conservation and Renewable Energy
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERN	Conseil Européen pour Recherche Nucléaire

CESAR	Center for Engineering Systems Advanced Research
CFC	chlorinated fluorocarbons
CFRP	Consolidated Fuel Reprocessing Program
CH	contact-handled
CIT	Compact Ignition Tokamak
CNAPCS	Center of Nuclear, Atomic, and Particle Computational Science
CoE	Center of Excellence
CORECT	Committee on Renewable Energy Commerce and Trade
CRESO	Clinch River Environmental Studies Organization
CURE	chemical unit risk estimate
CVI	chemical-vapor infiltration
D-T	deuterium-tritium
D&T	Development and Technology
DARPA	Defense Advanced Research Projects Agency
DHHS	U.S. Department of Health and Human Services
DNA	deoxyribose nucleic acid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE-ER	U.S. Department of Energy, Office of Energy Research
DOE-ORO	U.S. Department of Energy, Oak Ridge Operations
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DP	Defense Programs
DSRD	Data Systems Research and Development
DTP	Defense Technology Program
DTRC	David W. Taylor Naval Ship R&D Center
ECH	electron-cyclotron heating
ECR	electron-cyclotron resonance
ECUT	Energy Conversion and Utilization Technologies
EGF	epidermal growth factor
EH	Environment, Safety, and Health
EH&S	environmental, health, and safety
EIA	Energy Information Administration
EMAP	Environmental Monitoring and Assessment
EMIC	Environmental Mutagen Information Center
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
EPSSC	Environmental and Physical Science Study Center
ER	U.S. Department of Energy, Office of Energy Research
ESC	Ecological Study Center
ESD	Environmental Sciences Division
ETEC	Energy Technology Engineering Center
ETP	Emergency Technology Program
FDA	U.S. Food and Drug Administration
FE	Fossil Energy
FEDC	Fusion Engineering Design Center
FEMA	Federal Emergency Management Agency

FHWA	Federal Highway Administration
FIS	fluoroimmunosensor
FTE	full-time equivalent
FTMS	Fourier transform mass spectroscopy
FUSRAP	Formerly Utilized Sites Remedial Action Project
GCLA/ACM	Great Lakes Colleges Association/Associated Colleges of the Midwest
GPP	general plant project
GRI	Gas Research Institute
GSF	gross square feet
HASRD	Health and Safety Research Division
HAZWRAP	Hazardous Waste Remedial Action Program
HBCU	historically black colleges and universities
HE	high explosive
HEL	U.S. Army Human Engineering Laboratory
HERMIES	Hostile Environment Robotic Machine Intelligence Experiment Series
HFIR	High Flux Isotope Reactor
HHIRF	Holifield Heavy Ion Research Facility
HILI	Heavy-Ion-Light-Ion
HISTRAP	Heavy Ion Storage Ring for Atomic Physics
HLW	high-level waste
HPRR	Health Physics Research Reactor
HSDB	Hazardous Substances Data Bank
HTGR	high-temperature gas-cooled reactor
HTML	High Temperature Materials Laboratory
HWR	heavy-water reactor
HWTP	Hazardous Waste Technology Program
IAC	Information Analysis Center
ICE	independent cost estimating
ICRF	ion cyclotron range of frequency
IEUP	Integrated Electric Utility Program
INEL	Idaho National Engineering Laboratory
IPC	Isotopes Processing Complex
IRML	Isotopes Research Materials Laboratory
ITER	International Thermonuclear Experimental Reactor
IWMF	Interim Waste Management Facility
JAERI	Japan Atomic Energy Research Institute
JET	Joint European Torus
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LCP	Large Coil Program
LET	linear-energy transfer
LL	Lead Laboratory
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
LLWDDD	Low-Level Waste Disposal Development and Demonstration
LMR	liquid metal reactor
LOCA	loss-of-coolant accident

LTM	Laboratory Telerobotic Manipulator
LTNIF	Low-Temperature Neutron Irradiation Facility
LWR	light-water reactor
MEC	Model Energy Code
MEI	minority educational institution
MEOR	microbial-enhanced oil recovery
METC	Morgantown Energy Technology Center
MGPF	Multipurpose General-Purpose Facility
MHTGR	modular high-temperature gas-cooled reactor
MIRT	Minority Institution Research Travel
MMW	multimegawatt
MODIL	SDI Survivable Optics Manufacturing Operations Development and Integration Laboratory
MOU	memorandum of understanding
MS/MS	mass spectrometry/mass spectrometry
MSDS	Material Safety Data Sheet
NASA	National Aeronautics and Space Administration
NCA&TSU	North Carolina Agricultural and Technical State University
NCI	National Cancer Institute
NCSASR	National Center for Small-Angle Scattering Research
NCTR	National Center for Toxicological Research
NE	Nuclear Energy
NEESA	Navy Energy and Environmental Support Activity
NEPA	National Environmental Policy Act
NES	National Energy Strategy
NG	newly generated
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
NLM	National Library of Medicine
NMR	nuclear magnetic resonance
NMSS	Office of Nuclear Material Safety and Safeguards
NPR	New Production Reactor
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
NSF	National Science Foundation/Neutron Scattering Facility
OCRWM	U.S. DOE Office of Civilian Radioactive Waste Management
OEA	Office of Environmental Analysis
OGUI	Office of Guest and User Interactions
OHER	Office of Health and Environmental Research
ORACL	Oak Ridge Advanced Computing Laboratory
ORAU	Oak Ridge Associated Universities
ORELA	Oak Ridge Electron Linear Accelerator
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORGSBS	Oak Ridge Graduate School of Biomedical Sciences
ORNL	Oak Ridge National Laboratory
ORO	Oak Ridge Operations
ORR	Oak Ridge Reservation

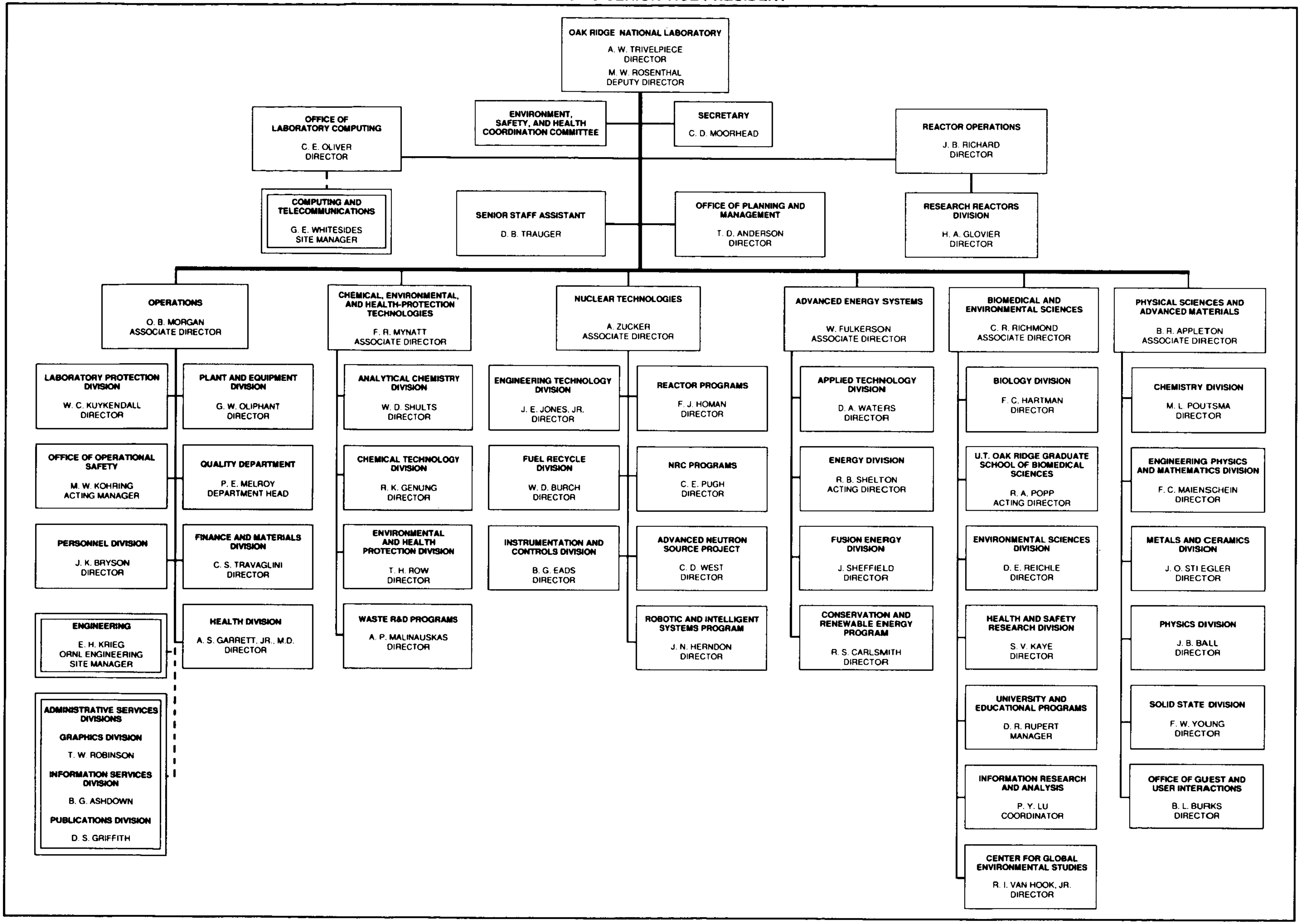
ORSERS	Oak Ridge Science and Engineering Research Semester
OTA	Office of Technology Applications
PC	personal computer
PCB	polychlorinated biphenyl
PE	Office of Planning and Analysis
PEIA	Programmatic Environmental Impact Analysis
PEIS	Programmatic Environmental Impact Statement
PETC	Pittsburgh Energy Technology Center
PNC	Power Reactor and Nuclear Fuel Development
PNL	Battelle Pacific Northwest Laboratories
PRISM	Partners for Resources in Science and Mathematics
PSP	Plasma Separation Process
R&D	research and development
RADCAL	Radiation Calibration Facility
RAP	Remedial Action Program
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	remotely handled
RIS	resonance ionization spectroscopy
RISP	Robotics and Intelligent Systems Programs
RMS	recoil mass separator
ROW	rest of world
RPP	Radiochemical Processing Plant
RSIC	Radiation Shielding Information Center
SAHEP	Southern Association of High-Energy Physics
SAMPE	Society for Advancement of Material and Process Engineering
SARA	Service Academy Research Associates Program
SCSS	Sequence Coding and Search System
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Office
SDT	Space and Defense Technology
SEED	Summer Educational Experience for the Disadvantaged
SERS	Science and Engineering Research Semester
SFMP	Surplus Facilities Management Project
SHaRE	Shared Research Equipment
SMAC/CRC	Surface Modification and Characterization/Collaborative Research Center
SNL	Sandia National Laboratory
SPC	Superconductivity Pilot Center
SPR	Strategic Petroleum Reserve
SRP	Savannah River Plant
SSC	Superconducting Supercollider
STAR	Summer Teachers as Resources

STEPS	Superconducting Technology for Electric Power Systems
STM	scanning tunneling microscope
STRIVE	Science Teachers Research for Vital Involvement
SURA	Southeastern University Research Association
SWSA	solid waste storage area
SYSRAP	System Reconfiguration and Analysis Program
TCRD	Tennessee Center for Research and Development
TDHF	time-dependent Hartree-Fock
TDP	Technology Development Program
TEAM	Technology-Based Enhanced Autonomous Machines
TEM	transmission electron microscopy
TEXTOR	Tokamak Experiment for Technical Oriented Research
TFTR	Tokamak Fusion Test Reactor
TIRC	Toxicology Information Response Center
TOXNET	Toxicology Data Network
TPP	Transuranium Processing Plant
TRA	Teacher Research Participation Program
TRU	transuranic
TURF	Thorium-Uranium Recycle Facility
TVA	Tennessee Valley Authority
ULCP	University Laboratory Cooperative Program
UMTRAP	Uranium Mill Tailings Remedial Action Project
UPR	the University of Puerto Rico
USDA	U.S. Department of Agriculture
UT	The University of Tennessee
UTK	The University of Tennessee, Knoxville
UV-B	ultraviolet-B
VISITS	Very Important Small Institution Travel Support
VMT	vehicle-miles-of-travel
WFO	Work for Others
WHPP	Waste Handling and Packaging Plant
WIPP	Waste Isolation Pilot Plant
WMTC	Waste Management Technology Center
WRDC	Wright Research and Development Center
WSDD	Waste Systems Data and Development

List of Figures

ORNL DWG-89-18402

REPORTS TO SENIOR VICE PRESIDENT



APPROVED (signature)

FOR INTERNAL DISTRIBUTION

ORGANIZATION CHART:

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA ENERGY SYSTEMS, INC.

EFFECTIVE DATE OCTOBER 1989

MARTIN MARIETTA

Acknowledgments

The *Institutional Plan* is the final product of the Laboratory's 1989 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.

DOE's involvement in ORNL's planning process helped shape this Plan, particularly at this year's On-Site Review when new initiatives were presented and vital issues were addressed. DOE-ORO staff provided guidance at each stage of the planning cycle. Special appreciation goes to ORO's Institutional Planning Manager, George C. Manthey.

In particular, we want to thank the individuals who contributed greatly to the production of this document. First and foremost we thank our talented and dedicated editor, Wanda G. Jackson, who has managed the production of three ORNL Institutional Plans. Assisting her in editing were Walter S. Koncinski, Jr., Ralph W. Sharpe, Patricia Mucke, and Carolyn Moser. Sandi Lyttle, our compositor again this year, did an exceptional job and did it quickly, as did Larry Davis, who handled the makeup of all the pages of the document. The talents of our graphic artists and photographers are gratefully acknowledged. Special thanks go to Vickie Conner for the cover design and to photographer Bill Norris. R. L. Hooks and his staff worked diligently with the editor to ensure a high-quality printed document.

In the Planning Office, Teresa Schubert, Dea Graves, and Janet Dippo made outstanding contributions during this year's planning cycle.

Beverly Y. Wilkes