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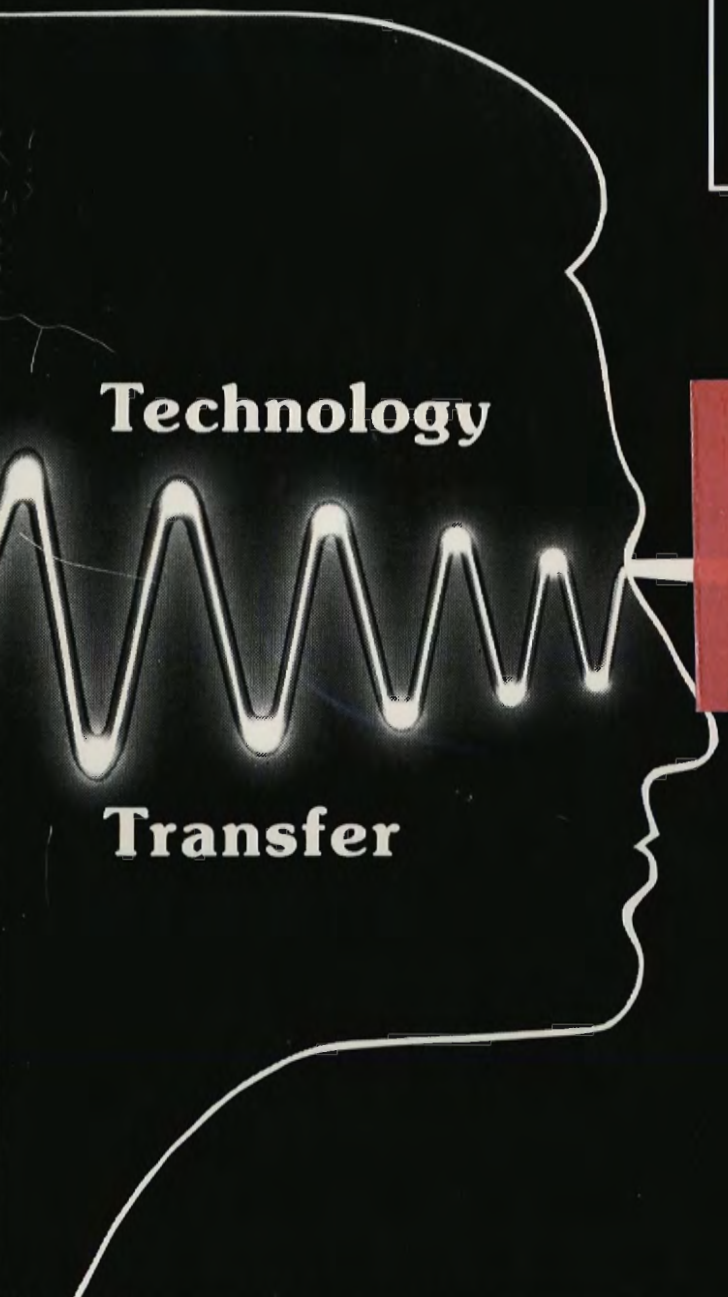
Oak Ridge National Laboratory Institutional Plan

FY 1989—1994



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Cover: Technology Transfer

Oak Ridge National Laboratory's vision of the future includes a focus on the active conversion of ideas into practical technologies and the effective transfer of those technologies to domestic industry in support of the United States' participation in world markets.

Cover design by Vickie L. Conner.

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OAK RIDGE NATIONAL LABORATORY INSTITUTIONAL PLAN FY 1989—FY 1994

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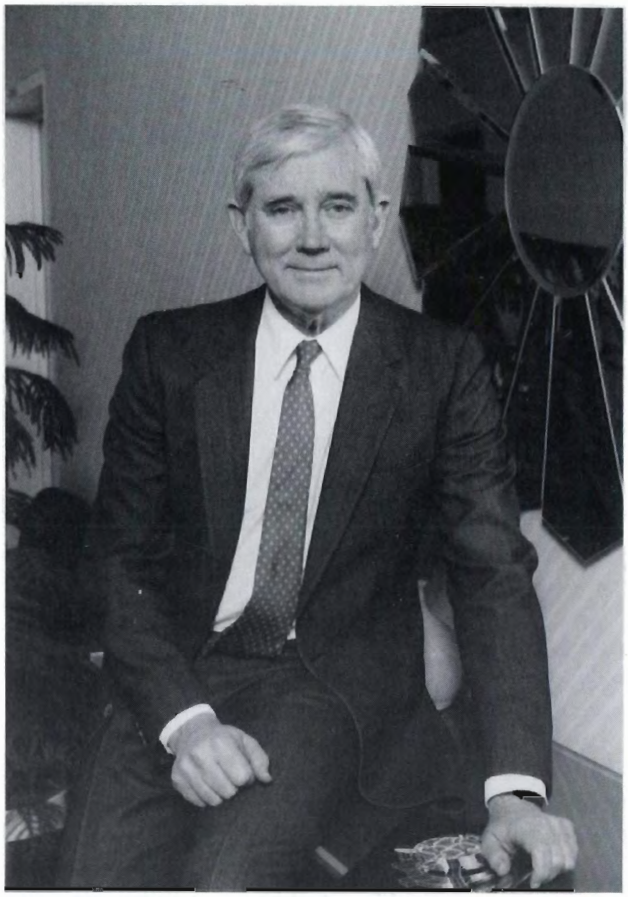
Laboratory Director's Statement

Laboratory Director's Statement



Alvin W. Trivelpiece
Director
Oak Ridge National Laboratory

This Institutional Plan was prepared prior to my arrival at ORNL. It contains a description of the programs now under way and those planned for in the future. It does not reflect any guidance on my part in terms of content or direction of the projects and programs. As the new Director of the Laboratory, I obviously have a strong interest in the Laboratory's programs and their success. ORNL has a long history of outstanding scientific, technical accomplishments and I will do everything I can to ensure that this continues into the future.

The past decade has witnessed a growing awareness of the connection between advances in science and technology and economic growth. It has also witnessed the growing concern that the United States is falling behind in its ability to compete in certain arenas of technology development. As a result, there has been an examination of many activities in our nation to determine what might be done to improve our ability to compete on a global scale. Competitiveness has become a buzz word.

Competitiveness begins at home. This includes ORNL. We need to continue to identify and conduct outstanding frontier programs of basic and applied research and technology development. Competitiveness means periodic critical review of these programs to ensure that they are excellent and consistent with the national needs. In that regard, ORNL and the other Department of Energy Laboratories have a vital role to play in various arenas involving competitiveness.

To enhance our competitive position in international commercial markets, better working relationships with industrial organizations will help to transfer knowledge about the Laboratory's scientific and technological developments. Our colleagues from industry can also help the Laboratory scientists to better understand industry problems that the Laboratory might help to solve. This type of synergistic relationship also exists between universities and the Laboratory. Jointly sponsored research and other interactions provide access to unique facilities and invigorating discussions. Also, to be competitive in the future, the DOE Laboratories and industries need sufficient technical staff. Closer ties with schools and universities can help this situation by

stimulating our youth, including minorities and women, to consider careers in science and engineering.

Another technology transfer mechanism available to bolster our industrial competitiveness is the Laboratory's availability to do work for other institutions. One of the better ways to transfer technology, as well as ideas, is through human interactions. With work for others (WFO) projects these interactions happen naturally. The WFO program allows the Laboratory to develop prototypes of equipment, software, artificial intelligence and other technologies for industries and other government agencies. It is also a means to further develop laboratory-invented technologies and bring them closer to commercial viability. These projects require the unique facilities and interdisciplinary staff of the Laboratory that are otherwise not commercially obtainable. By definition, the projects must be consistent with the DOE mission and follow DOE guidelines. Again, the competitiveness of both the outside institutions and the Laboratory is enhanced. These outside institutions may gain new knowledge, a new prototype or experience with a new technique. Through the WFO program, the Laboratory gains through the expansion of the staff's experience and the interactions with the other institutions.

The Laboratory has an important role in the operation of unique scientific facilities needed to make progress on the frontier of many scientific and technical fields ranging from fundamental physics to the discovery of new engineering materials. These major facilities provide opportunities for scientists to pursue avenues of research that cannot otherwise be followed. The Advanced Neutron Source, proposed for construction at ORNL, is one example. The ANS will provide a new, world class research reactor for neutron research and isotope production.

Remaining competitive also requires adequate facilities to house equipment and staff. An ongoing challenge for the future will be the replacement of aging structures at all DOE Laboratories. ORNL is not an exception. In addition, computers have become an essential part of most scientific endeavors. It is important to maintain modern equipment with the computing power necessary for the large problems surfacing in the physical and life sciences, as well as the large data bases needed for many technological fields.

The Laboratories are a key part of the solution of the critical problems of our times. The multidisciplinary environment allows a coordinated approach to the investigation of issues such as global warming, design of a new generation of passively safe reactors, industrial and nuclear waste management, and the development of new energy sources. ORNL has the staff, the facilities, and the vision to make a contribution to the solution of these and other scientific and technical challenges.

Laboratory Missions

Laboratory Missions

The Oak Ridge National Laboratory (ORNL) is one of the U.S. Department of Energy's (DOE's) major multiprogram energy laboratories. ORNL's program missions are (1) to conduct applied research and engineering development in support of DOE's programs in fusion, fission, conservation, fossil, and other energy technologies and (2) to perform basic scientific research in selected areas of the physical and life sciences. 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 (R&D), and selected defense technologies. In addition to the R&D missions, ORNL performs very 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 stellarator confinement configurations, plasma heating, fueling systems, superconducting magnets, first-wall and blanket materials, and applied plasma physics. The ORNL nuclear fission activities support DOE's civilian nuclear power program through R&D on nuclear fuel reprocessing, high-temperature gas-cooled reactors (HTGRs), instrumentation and controls, nuclear and chemical wastes, and materials. The Laboratory's program on conservation and renewable energy emphasizes research on high-temperature materials, electric power distribution systems, conservation technologies for buildings and industry, biomass production, and energy storage. ORNL's fossil energy work concentrates primarily on materials and on innovative research in coal conversion and utilization. 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 physics.

The role of providing user facilities for industry and universities encompasses over a dozen major installations including the Neutron Scattering Facility (NSF), the National Center for Small-Angle Scattering Research (NCSASR), the Holifield Heavy Ion Research Facility (HHIRF), the High Temperature Materials Laboratory (HTML), the Surface Modification and Characterization Collaborative Research Center (SMAC/CRC), the Health Physics Research

Reactor (HPRR), 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

Laboratory Strategic View

The Oak Ridge National Laboratory (ORNL) "Strategic View" is an expression of long-range (15-year) goals by the Laboratory's senior management. 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 research and development (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 likely 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; if the United States is to meet the challenge of global economic competition, the nation must call upon all of its intellectual resources—universities, industry, and national laboratories—to work together toward a common goal.

The U.S. Department of Energy (DOE) and its energy R&D 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; most observers believe that the mobilization of these resources is a key ingredient to the future health of U.S. industry. Another reason DOE and its energy 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.

In another area important to DOE, 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. Results from R&D work directed toward DOE's waste problems will, in many instances, be transferable to national waste problems.

Concurrent with the worsening energy and trade trends and the increased emphasis on wastes, there 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 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. 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 not only be permitted but 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.

Laboratory Environment

During the next 15 years, 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 will remain the central theme, major roles will be encouraged by DOE in other areas, especially in 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 (NRC). Work for other government agencies and for private industry will be permitted and 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 along the lines suggested in Figs. 1 and 2. There will be an increase in size, more emphasis on major technological missions in energy and other commercially important technologies, and an increase in waste R&D work. Selected areas of defense will also be supported when this work is closely related to the civilian R&D missions. Slight changes in sponsorship will occur over the planning period with the most notable shift being an increase in work for private industry.

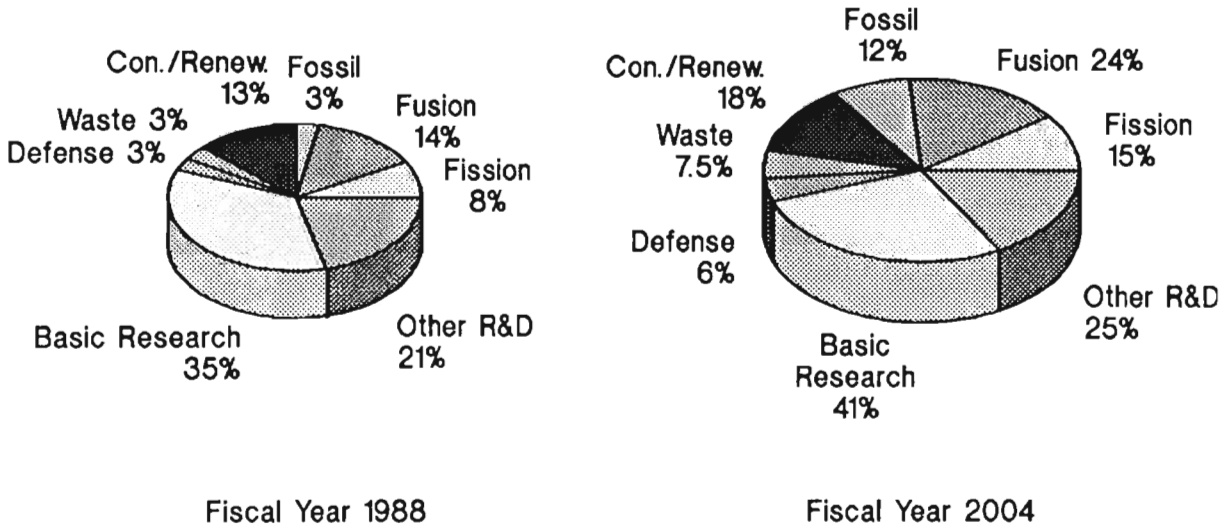
As a consequence of the emphasis on collaborative R&D, guest researchers at ORNL will continue to increase over the planning period as shown in Fig. 3. By FY 2004, the number of guest researchers will approach 4500, more than double the number (2173) for FY 1987. Much of the increase in collaboration with outside researchers will be associated with the expansion of existing user facilities and the addition of new facilities. Major new facilities planned over the next 15 years will include the Advanced Neutron Source (ANS), the Heavy Ion Storage Ring for Atomic Physics (HISTRAP), and some important experimental fusion facilities.

Energy Technologies

The Laboratory will strive for strong, balanced programs in all four of the major energy technology areas—conservation, fusion, fission, and fossil.

Conservation and Renewables

In conservation and renewables R&D, the long-term goals are to (1) maintain a broad-based conservation/renewables program, (2) continue the dual role of in-house research and program management, and (3) expand interactions with



Values are % of total R&D effort in 1988

Fig. 1. Research and development activities (1988–2004).

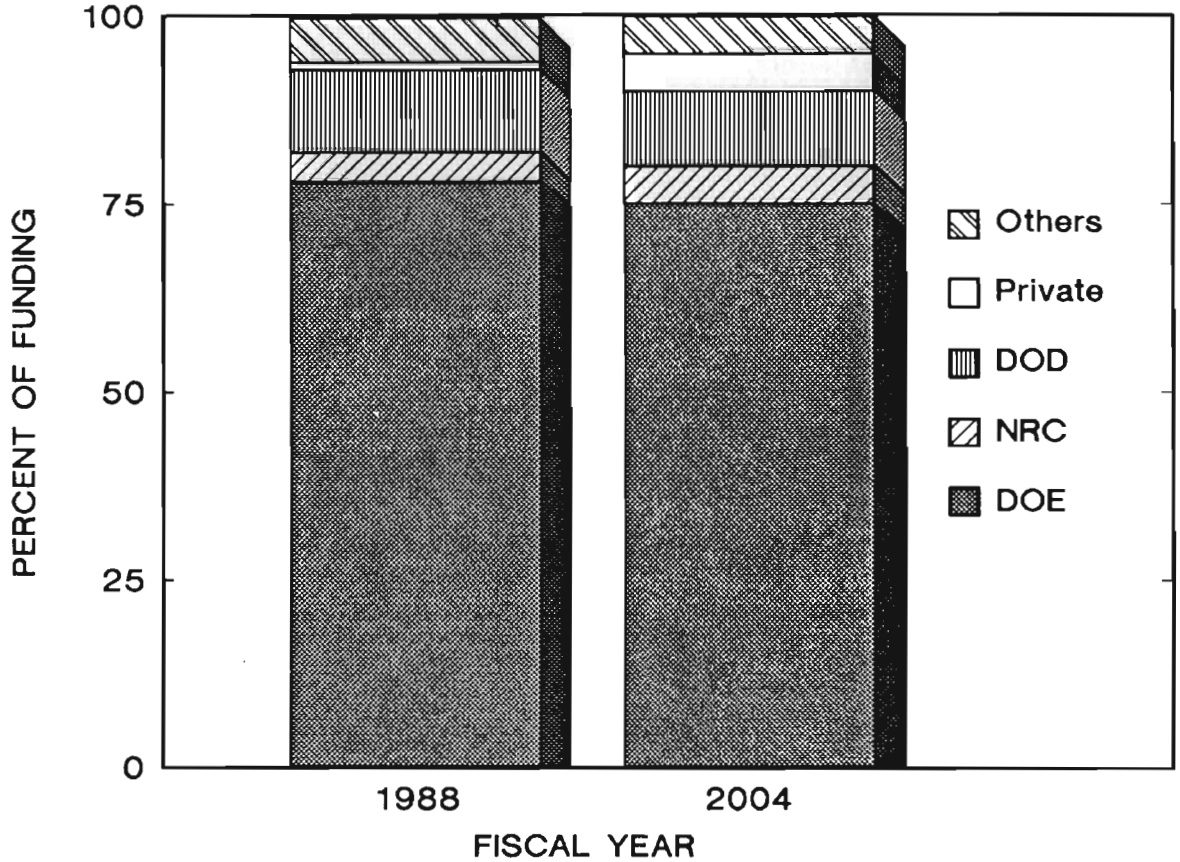


Fig. 2. Sponsors of research and development at ORNL (1988–2004).

industry. The scope of the planned program includes R&D in the following areas.

- Buildings
  - equipment
  - envelopes and materials
  - integrated concepts (e.g., the "smart house" concept)
- Materials
  - Energy Conversion and Utilization Technologies (ECUT) materials
  - ceramic technology for heat engines
  - materials for heat recovery
  - High Temperature Materials Laboratory (HTML) user centers
- Biomass
  - production
  - conversion
- Other
  - industrial chemical heat pumps
  - alternative fuels utilization
  - power systems technology
  - thermal energy storage

Fusion

The long-term strategy for fusion is to stress scientific and engineering excellence in a broad program emphasizing technology and materials.

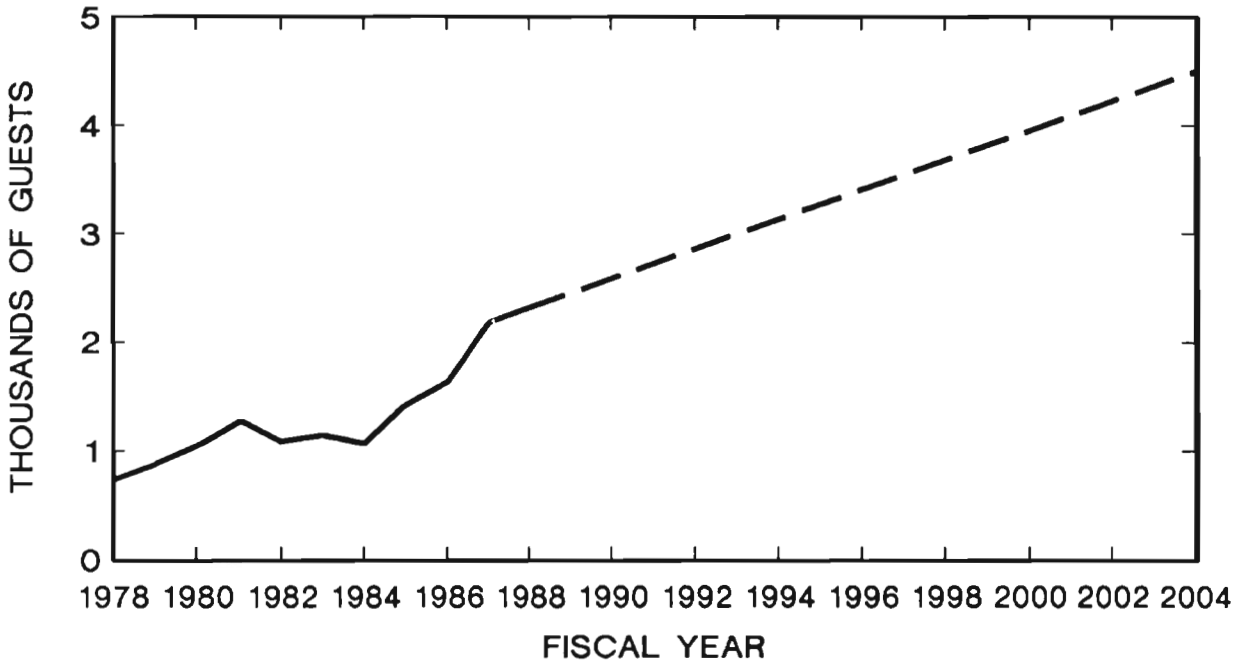


Fig. 3. Guest researchers at ORNL (1978–2004).

ORNL's major 15-year goals in fusion are to:

- maintain leadership in advanced plasma technology components,
- establish a strong program in remote technology for fusion,
- lead the world in materials development and testing for fusion reactors,
- maintain U.S. leadership in stellarators, and
- build major fusion facilities in Oak Ridge including an upgraded Advanced Toroidal Facility (ATF) and ATF-2.

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 (LWRs), 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; and
- probabilistic risk analysis.

Fossil

The planned directions for fossil energy reflect the Laboratory's deep-seated, long-term conviction that fossil energy, especially coal, is one of the nation's most important subjects for R&D. Fossil energy R&D will focus on three important areas: materials; environment, health, and safety; and

innovative coal processing concepts. Materials work will include:

- fundamental research on materials erosion and corrosion;
- alloys for high-temperature, advanced steam cycles;
- fiber reinforced ceramics for high-temperature combustors and hot gas filters;
- ceramic membranes for gas separation; and
- materials for advanced fossil technologies including coal liquefaction and gasification, combustion, heat engines, and fuel cells.

Work on environment, health, and safety will include support for clean coal projects and the development of information systems. Innovative coal processing concepts will include microbial liquefaction and gasification.

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 both chemical and radioactive wastes. One area of emphasis will be on expanding the Waste Management Technology Center (WMTC).

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.

Physical Sciences

Areas of research in the physical sciences will include:

- materials;
- computations;
- robotics and intelligent systems;
- nuclear and atomic physics; and
- the chemical sciences.

The goals of the Laboratory's materials program are to achieve world leadership in high-temperature materials development and to excel in certain areas of solid state physics including surface research, preparation of new materials, advanced materials 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. In atomic physics, the addition of HISTRAP will extend the research program to frontier energy regions. 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 and the environmental sciences—will continue as essential elements of the Laboratory's activities throughout the 15-year strategic planning period. In biology,

the plan is to build on the core areas of:

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

In addition, it is planned to expand multidisciplinary research in structural biology and genome mapping. In the environmental sciences, the broad goal is to retain the Laboratory's status as the nation's premier ecological-environmental research center. The environmental sciences program will cover both energy-related environmental issues and global science. An important objective is to study and understand the interactions of physical and chemical agents with living organisms, including transport, chemical evolution, adverse health effects, and ultimate consequences in humans and their environment. Important long-term goals in environmental research include:

- anticipating future environmental problems,
- understanding atmosphere-biosphere boundary interactions and feedbacks,
- improving time-space scaling of nonlinear environmental systems and regional extrapolation,
- developing predictive environmental models,
- understanding mechanisms of subsurface transport,
- understanding global environmental systems, and
- quantifying environmental risk and cumulative effects.

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, human resources, and administration.

Central to accomplishing the missions outlined in this plan is the acquisition of key research facilities. Senior managers in DOE and ORNL will need to pay especially close attention to moving these facilities from plans to reality. The ANS is of critical importance to a number of the Laboratory's research areas including materials, nuclear physics, biology, and the chemical sciences. The HISTRAP is the key 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 Advanced Control Test Operation (ACTO) program. Completion of the Life Sciences Complex is essential to achieving the biological research objectives of this plan. An important addition to the Life Sciences Complex is the Molecular Genetics Laboratory.

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.

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 employees, but a larger component will be from growth in the number of guest researchers.

As education and training activities expand it becomes important to institutionalize those activities through formal funding mechanisms and by the acquisition of programmatic space. This is especially true in the proliferating area of precollege programs.

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

New Initiatives

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 several 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. 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. Three pilot-scale HTGRs (Dragon in the United Kingdom, Peach Bottom in the United States, and the AVR in Germany) and two demonstration-scale HTGRs (Fort St. Vrain in the United States and THTR in Germany) have been built and operated. A poor economic climate in the mid-1970s and escalating capital costs for nuclear plants resulted in cancellation of all HTGR orders by 1977. The HTGR technology-development program was reduced to a maintenance level and was kept alive largely because of interest in Congress.

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 (Fig. 4). 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

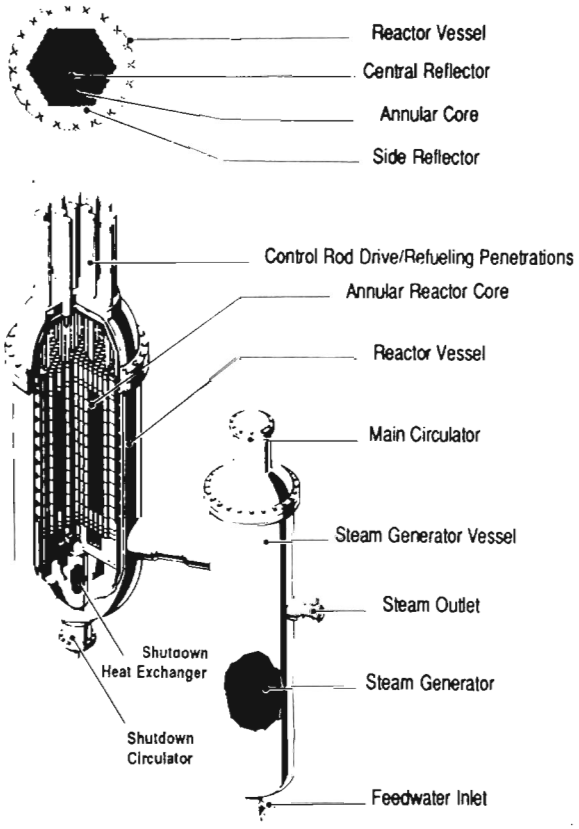


Fig. 4. Modular high-temperature gas-cooled reactor steam supply system.

to the ground. The core temperature will not rise above 1600°C, a temperature which the fuel can survive without significant damage. This feature of passive safety offers many advantages.

- It avoids the need for emergency evacuation and sheltering plans.
- It provides a degree of investment protection; a plant can restart after an "accident."
- It eliminates the need for expensive redundant safety systems; the cost savings that result partly compensate for higher costs caused by the smallness of scale.
- The small core of the MHTGR can be housed in a steel pressure vessel, which can be fabricated in a factory; reduction of field fabrication also provides cost benefits.

The Oak Ridge National Laboratory's (ORNL's) role in this new initiative is in the area of technology development. Responsibility for MHTGR technology development has been consolidated, as has design responsibility. 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 includes seven specific components:

- *Fuel performance.* Performance data on MHTGR-quality fuel (20 times better than previous HTGR fuel) will be collected by performing capsule tests in the High-Flux Isotope Reactor (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 fuel performance and fission-product 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.
- *Graphite behavior.* The core material, reflector material, and core support structure are all graphite. Knowledge of graphite properties, including statistical variation in properties, is required for the probabilistic risk analysis (PRA) that must be submitted as part of the licensing package.
- *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 design validation are required.
- *Safety analyses.* Validation of the physics design tools and the thermal hydraulics codes is required for licensing.
- *Shielding analyses.* The MHTGR has several unique shielding problems. The shielding for gas-cooled reactors must protect the reactor vessel and core internals from neutrons that "stream" through control rod drive penetrations. In contrast, the coolant in water-cooled and sodium-cooled reactors provides some shielding, reducing the scope of this problem. Also, the

relatively low-power density MHTGR core, which is beneficial for passive safety, reduces space for shielding between the core and the vessel. 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 the international cooperation is also the responsibility of the Technology Development Program (TDP).

Costs for technology development are estimated at $75 million. An estimated $25 million more will be needed for component testing. The TDP plan, which was completed in 1986, 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 1).

Table 1. Budget projection by fiscal year for MHTGR Technology Development

($ in millions)

1988	1989	1990	1991	1992
6.3	4.9	8.8	12.0	12.0

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.

Microwave Sintering of Ceramics

The use of microwave radiation promises to revolutionize the processing of a wide range of materials. We have concluded that sintering of ceramic powders using a novel microwave furnace, which was invented by an ORNL staff member, is a particularly important area. Using monies from the ORNL director's research and development (R&D) fund and equipment available from a fusion energy experiment, an interdisciplinary team of ORNL scientists built and operated the furnace during FY 1987. Experiments were performed to characterize the sintering behavior of aluminum oxide using 28-GHz radiation as the energy input. It was discovered that the apparent activation energy for sintering of alumina in the 28-GHz microwave field was only 170 kJ/mol, as compared to 575 kJ/mol for conventional heating. Alumina powder compacts were densified at temperatures 400°C lower than those required for comparable densities with conventional heating.

At this time there is no explanation for lowering the temperature required to densify alumina using microwave radiation. However, the implications resulting from the use of microwave radiation in the ceramics industry are quite clear. Lower temperatures offer the potential for avoiding some undesirable chemical effects, such as thermal decomposition, in the consolidation of materials that are difficult to sinter. Lower temperatures also offer the possibility of new material combinations for applications such as semiconductor packages. Because of the volumetric, uniform heating produced by microwaves, more rapid production cycle times may be possible. This

may also be important for low-thermal-conductivity assemblies such as advanced fuel cells. In addition, the ability to selectively heat mixtures of materials will make possible new microstructures that are unattainable with conventional heating.

Our results at both 28 GHz and 2.45 GHz clearly show that microwave processing could produce a competitive advantage in ceramic manufacturing. The literature shows that our international competitors are working to exploit microwave technology in many segments of their materials industries. Some competitors, particularly France, Canada, and Sweden, have placed such great emphasis on microwave and radio frequency (rf) heating (electrotechnologies) that entire departments of government agencies are devoted to research, development, and implementation of these technologies.

To ensure that the United States maintains a competitive advantage in electrotechnologies in the near future, ORNL proposes to form an industrial consortium on the microwave sintering of ceramics. A major goal of this consortium would be the transfer of microwave sintering technology to U.S. industry in a timely manner. Technology transfer would be expedited by working with industry early in the R&D cycle rather than after intellectual property is in the public domain. Initial interest has been shown by several major ceramic manufacturers. Researchers from U.S. industry would initially monitor sponsored research performed by ORNL staff members. Eventually, on-site industrial participants would collaborate with ORNL staff members. Both jointly funded generic and individually funded proprietary research would be allowed under the guidelines of the consortium.

The potential of this technology gained the interest of programs in fossil energy, defense programs, and conservation and renewable energy for FY 1988. It was initially supported under the ORNL Exploratory Studies Program with $30 thousand in FY 1986 and an additional $338 thousand in FY 1987. Funding for FY 1988 was $1.3 million from various sources including $700 thousand of direct DOE support for investigating the densification of alumina, silicon nitride, high-temperature superconductors, and lithium hydride.

DOE funding in FY 1989 is providing support for the near-term R&D program objectives, concentrating on the development of the following:

- 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;
- a less expensive source of microwave power in the 28-GHz range that would make microwave sintering at higher frequencies more economically feasible;
- repeatable and reliable heating and insulating techniques for microwave sintering of new materials;
- diagnostic tools, instrumentation, and techniques for the process control of microwave sintering; and
- a predictive engineering model for microwave furnace and process design.

This support and projected future needs, both operating and capital, are indicated in Table 2. In addition, substantial support from other agencies, including private industry, is being sought and is expected.

Table 2. Direct DOE budget projections by fiscal year for Microwave Sintering

($ in millions)

	1988	1989	1990	1991	1992
Operating	0.7	1.4	3.4	3.9	4.3
Capital	0.0	0.0	1.5	1.5	1.5

A strong, jointly funded Department of Energy (DOE) and industry research program at ORNL will allow the United States to stay ahead of our international competitors in the very rapidly evolving field of microwave sintering technology.

Bioprocessing in Fossil Energy

Bioprocessing is expected to make important contributions to several aspects of the use of fossil energy and to enhance the use of these 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 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, conversions into chemical products, etc.), there are several similar aspects to potential bioprocessing. A coordinated program at ORNL would provide useful interactions between related studies and would eliminate unnecessary duplication of effort.

Roles of Bioprocessing in Fossil Energy

Coal Preliminary studies have shown that bioprocessing can be useful in beneficiation of coal to remove sulfur and other "heteroatoms," to liquefy/solubilize coal, to activate the coal for more effective subsequent liquefaction or gasification, and to upgrade liquids and gases produced from coal. The research in each of these areas is relatively new, and ideas and understanding are still developing. Because many of these applications involve organisms and enzymes that are capable of attacking specific portions of the coal or coal-derived molecules, advances in each area will provide insight that can assist in other areas.

The use of bioprocessing in environmental control technology for coal conversion facilities has been demonstrated at the pilot-plant level, and demonstration plants were operated during the last decade for coal liquefaction and gasification. Biotreatment of wastewaters has been successful, and additional applications of bioprocessing to clean up product liquid spills, to treat solid residues, and possibly even to remove acid components from process off-gases may be developed.

Oil and Gas Recovery and Processing Microbial-enhanced oil recovery (MEOR) is an interesting and promising way to use bioprocessing to increase the production of oil. Experimental injection of organisms and nutrients into oil fields has resulted in increased oil production. Our understanding of what happens in MEOR is extremely limited, and our ability to predict when or how much improvements in oil yield can be expected via MEOR is poor.

Bioprocessing can also have several other uses in oil recovery and processing. Microbes can be used to produce chemicals such as polymers, surfactants, alcohols, and acids in bioreactors that are useful in enhanced oil recovery by chemical flooding. The relative merits of producing these chemicals in surface facilities and in situ (as in MEOR) are not known. Bioprocessing may also be useful in upgrading oil products to remove heteroatoms or otherwise alter the molecular structure. Microbial gasification of coals or oils that would otherwise be difficult to recover may also be a possibility.

Bioprocessing in oil and gas also has a potentially important role in environmental control. Wastewaters, spills, and even off-gases may be treated by bioprocessing. The floodwaters produced in oil recovery operations are additional streams that could benefit from biological treatment, especially if floodwaters must be reused or disposed of in more costly controlled wells.

There are numerous similarities between the bioprocessing opportunities and research needs for coal, oil, and gas. These are only the most evident reasons why coordinated research in bioprocessing can enhance the work in all areas.

Shale Oil Recovery Although our domestic supplies of potential oil in shale are large, the cost and possible environmental impact of shale development have prevented large-scale development of this resource. Bioprocessing offers several potential benefits to improve the outlook for shale. Biological extraction of oil (either in situ or in surface facilities) could be less energy intensive and thus recover more oil per unit of shale mined. It could also reduce the capital costs when compared to large thermal recovery facilities. As with oil production and coal liquefaction, bioprocessing may be useful in upgrading the liquid oil products by removal of heteroatoms or by desirable molecular rearrangements.

The roles of bioprocessing in environmental control for shale oil production are similar to those in oil processing and coal liquefaction and include wastewater treatment, cleanup of spills, and possibly off-gas cleanup. However, the potential importance of bioprocessing to treat solid residues may be even more important in shale oil production than in the other similar operations. This is principally because of the larger volume of solid residue.

Tar Sands The potential roles of bioprocessing in extracting useful oils from tar sands are similar to those discussed for the other potential liquid fuel sources. These include possible biological extraction of the heavy oil, upgrading of the liquid product, and cleanup of wastewater, off-gas, spills, and solid residue. The very "heavy" nature of the oils in tar sands makes the need to alter the molecular structure to form a lighter oil even more desirable. The importance of solid residue treatment for tar sand development is particularly important because of the large quantities of solids that must be removed from the ground for surface processing.

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 a center for bioprocessing research that will also include a bioprocessing research users facility available for use by national laboratories, universities, and industry. A significant emphasis will be placed on research that is carried out in cooperation with other energy laboratories, universities, and industry. To that end, ORNL will provide overall management of a coordinated program that will include a significant fraction of subcontracted research. ORNL would also sponsor workshops, meetings, and publications to ensure that all portions of the program benefit from the accomplishments and to ensure an aggressive technology transfer effort. Table 3 shows the proposed budget.

Table 3. Budget request by fiscal year for Bioprocessing in Support of Fossil Energy Applications

($ in millions)

	1989	1990	1991	1992	1993	1994
Operating	1.0	5.0	8.0	9.0	12.0	15.0
Capital	0.2	0.5	0.8	0.9	1.2	1.5

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 fifth and sixth years. The latter increases are expected to be needed to establish technical feasibility of concepts previously developed.

Center for Computer-Enhanced Scientific Productivity

The U.S. international competitive position could be strengthened by improving the productivity of our scientists—enabling geographically distributed interdisciplinary teams to more effectively solve computationally intensive (sometimes called "grand challenge") problems using advanced computer architectures.

Advanced computer technology is providing new computing architectures, larger and faster computers, and dramatically improved desktop models at increasingly lower prices. Among these new architectures are massively parallel computers, which are beginning to offer the capability to solve some of the grand-challenge problems. However, rather heroic measures are often required to obtain the near-maximum performance promised by these newer architectures—thus restricting their early use to a small subset of the researchers who could potentially benefit. To increase the usefulness of these computers in scientific research, two classes of researchers need to be dealt with: (1) the computer scientist, who will do whatever is necessary to achieve maximum performance on a new architecture; and (2) the typical researcher, who needs much more computing capability to effectively solve his research problem but cannot devote the time away from his research to master each new architecture that offers promise.

Training and education need to be developed to assist more researchers in learning to use new architectures to their maximum effectiveness. In addition, the non-guru researcher could benefit by the development of a scientifically distributed computing environment that would provide mathematical libraries tailored for optimum performance on massively parallel computers available transparently to the researcher. The appropriateness of new architectures for various classes of scientific problems needs to be determined; and the formation of interdisciplinary teams consisting of experts in parallel architectures and algorithms, along with experts in potential scientific applications, needs to be encouraged.

Strategies for accomplishing these objectives include the following:

1. Provide systematic investigations of new computer architectures and their applicability to specific scientific problem areas.
2. Provide a center where algorithms are developed for targeted "global-challenge" problems using massively parallel computers.
3. Provide verified and tested library functions on appropriate architectures available for remote execution through high-bandwidth communications.

4. Develop training and education methods for improving the ability of researchers to use the potential of the new architectures.
5. Develop and implement a user-interface and high-bandwidth communication methods to assist interdisciplinary research teams in using the power of massively parallel computers to formulate and solve grand-challenge problems.

To carry out these strategies, many diversified skills are needed. A noteworthy feature of Martin Marietta Energy Systems, Inc., and the surrounding area is the availability of a large population of experts in many of the fields needed. Expertise will be needed in the following areas: parallel computing algorithm development; network hardware and software development; artificial intelligence; user interfaces; data base design; security; and user training. The areas where much of this expertise is located include Mathematical Sciences, Instrumentation and Control, Computing and Telecommunications, robotics, ORNL's research divisions, Data Systems Research and Development (DSRD), The University of Tennessee, and area industries.

A sampling of the numerous grand-challenge problems identified at ORNL that would be addressed initially includes the following:

- electron correlation in high-T_c superconductors,
- lepton pair production in relativistic heavy ion collisions,
- theory of ground-state properties of ordered and disordered alloys and ordering processes in alloys,
- ab initio investigation of fracture in superlattice structures,
- visualization in scientific computing, and
- neutronics for the Advanced Neutron Source (ANS).

Exploratory funds have been used by ORNL to support innovative work in computations. DOE-supported work has enabled the development of a set of basic computational kernels that have assisted ORNL in becoming a recognized leader in algorithm development for parallel computers. In FY 1989, Director's R&D funds are being used to initiate development of a multidisciplinary team to address two of the grand challenges. The experience gained in this project, along with the expertise from the many other supportive activities described, will well prepare ORNL for scaling up to a resource level appropriate for a Laboratory-wide impact of enhanced scientific productivity through advanced computation. The technology transfer activities and multidisciplinary problems routinely dealt with by ORNL establish an environment conducive to addressing the challenges offered in this initiative. The anticipated budget is shown in Table 4.

Continuing Initiatives

Advanced Neutron Source

The development of the reactor and associated facilities for the ANS is an ongoing ORNL

Table 4. Budget projection by fiscal year for the Center for Computer-Enhanced Scientific Productivity

($ in millions)

1990	1991	1992	1993	1994
4.0	4.5	5.0	5.0	5.0

initiative. The ANS will return to the United States the leadership in neutron research, especially in neutron scattering research, that was lost to Europe in the early 1970s when the superb facility at the Institut Laue Langevin in Grenoble, France, became operational.

The capabilities of the ANS will greatly exceed those at any other facility of this type that is currently in operation or planned. It will consist of an advanced reactor with capabilities for neutron scattering work, isotope production capabilities, and materials irradiation positions. Neutron scattering research in the fields of condensed matter and chemical physics, polymer and colloid studies, biological research, nuclear physics, and materials investigations (Fig. 5) is the main scientific justification for the project, but the ANS will also include isotope production and materials irradiation capabilities as good as, or better than, the HFIR.

The ANS will be operated as a user facility for industry, academia, and government. A National

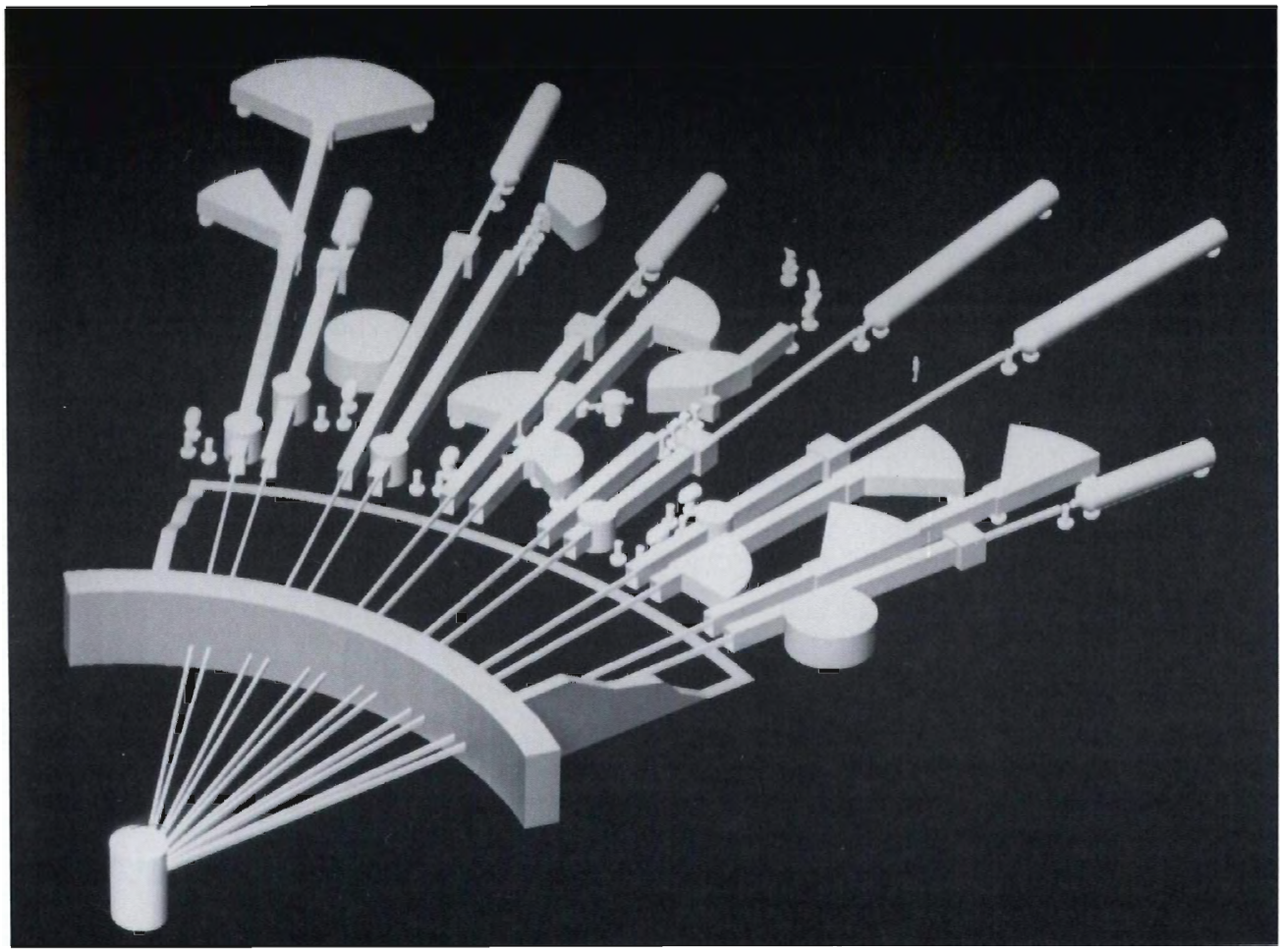


Fig. 5. The Advanced Neutron Source guide hall and cold neutron instruments (CAD drawing). Standing figure (upper right) is 2 m tall.

Steering Committee for the ANS (NSCANS) has been providing guidance in user needs and priorities.

The R&D program and preconceptual design activities for the ANS have received funding from Basic Energy Sciences (BES) for the past 2 years. The research program concentrates on verifying the feasibility of certain major design features, including the performance of aluminum-clad cermet fuels with unprecedented neutron and heat fluxes. Investigations of technologies that might further enhance performance and safety beyond the basic criteria are also under way, including studies of improved cooling systems, inherent safety features, and the advantages and penalties of reduced fuel enrichment.

Current cost estimates include an additional $35 million in pre-line-item R&D design funds and $412 million (1988 dollars) in line-item funding for detailed design and construction. In addition, $20 million in R&D funds will be needed during construction to support the design and safety analysis work (Table 5).

High-T_c-Superconductor Research and Development

Recent discoveries of new superconducting materials with high critical temperatures have generated interests 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 films and wires 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.

Table 5. Budget projection, for the planning period, by fiscal year for the Advanced Neutron Source

(in thousands of constant 1988 dollars)

Fiscal year	1988	1989	1990	1991	1992	1993	1994
Operating funds	3,673	8,700	9,552	4,000	4,000	4,900	4,900
Design-only line-item capital				9,500	10,000	14,600	
Construction line-item capital							39,512
Total	3,673	8,700	9,552	13,500	14,000	19,500	44,412

In addition to the basic and applied research, ORNL has several applications assessment projects under way related to high-T_c-superconducting materials. One of these is a detailed assessment of the potential energy savings applications of the newly discovered materials that are superconducting above liquid nitrogen temperatures. Other current projects are the evaluations of three specific applications: electric motors, power transformers, and magnetic separation. Some funding also supports the evaluation of ceramic superconductors for applications in fossil energy systems.

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) and serves as the lead laboratory for coordinating BES work in this area. During the spring of 1988, ORNL was named one of three DOE Superconductivity Pilot Centers (DOE-SPC). The purpose of these pilot center projects is to enhance interactions involving the new high-T_c 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 the high-T_c-superconductor research at ORNL is expected to grow to about $7 million in FY 1989, including $2 million to support the DOE-SPC. Because of the potential for applications of high-T_c-superconducting materials, this research area needs to grow substantially (Table 6).

Genome Mapping and Sequencing

An important continuing initiative is to develop new or improved methods for deoxyribonucleic acid (DNA) sequencing and analysis. 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.

The objective of this initiative 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 specific regions of the mouse genome; (2) analysis of the molecular structure and effects of heritable, agent-induced mutations; (3) creation of molecularly tagged

Table 6. Budget projections by fiscal year for research and development and High-Temperature Superconductivity Pilot Centers

(includes both new and redirected funds; $ in thousands)

Fiscal year	1988	1989	1990	1991	1992	1993	1994
Research and Development	4,000	4,000	5,000	5,000	5,000	5,000	5,000
Superconductivity Pilot Center (SPC)[a]	0	2,000	5,000	10,000	10,000	12,000	12,000

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

mutations throughout the murine genome by insertional-mutagenesis techniques; and (4) application of mutagenesis techniques to screen for models of important 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 plan to complement the biological research activities by developing new sequencing technologies with the private sector and establishing a data management system, possibly using parallel processing. Refer to Table 7 for budget projections.

Table 7. Budget projection by fiscal year for Genome Mapping and Sequencing

($ in millions)

1989	1990	1991	1992
2.6	3.3	3.3	3.5

The wealth of heritable mutations of the mouse, generated by radiation and chemical mutagenesis and maintained in large breeding stocks at ORNL, offers many opportunities for this type of molecular structure-function analysis and is the single most important asset of this initiative. The expertise of the staff in aspects of molecular genetics, transmission genetics, and mutagenesis is a vital component.

The human genome endeavor will require major effort in various types of data access and analysis. The sites for computerization of the actual sequencing data have been chosen. However, the overall information management and dissemination processes for this large, geographically dispersed program require meticulous preplanning of information systems. This will serve two functions: it will avoid generation of redundant data and proliferation of separate systems that will not interact with each other and it will ensure that all current information needs are met and that future needs are easily added.

ORNL plans to develop a system of communication tools to facilitate sharing of data across the human genome program. Additionally, a Management Information System (MIS) will be established in which data elements are defined to allow easy reporting; that is, anyone given official access to the system can quickly compile budget, literature, research in progress, related research, public relations, or other information into a timely meaningful report that is tailored to fit individual needs. From the MIS, research and management topics will be identified for in-depth analysis and reporting.

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.

The proposed HISTRAP facility (Fig. 6) will be associated with the Holifield Heavy Ion Research Facility (HHIRF), which is 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 (ECR) source. Development of this project continued in FY 1988 with design and prototype construction of difficult and long-lead-time major components of the device using ORNL director's exploratory R&D funds and Physics Division resources. A vacuum test stand equivalent to one-half of one straight section (1/16) of the proposed octagonal ring has been assembled and used to demonstrate the best

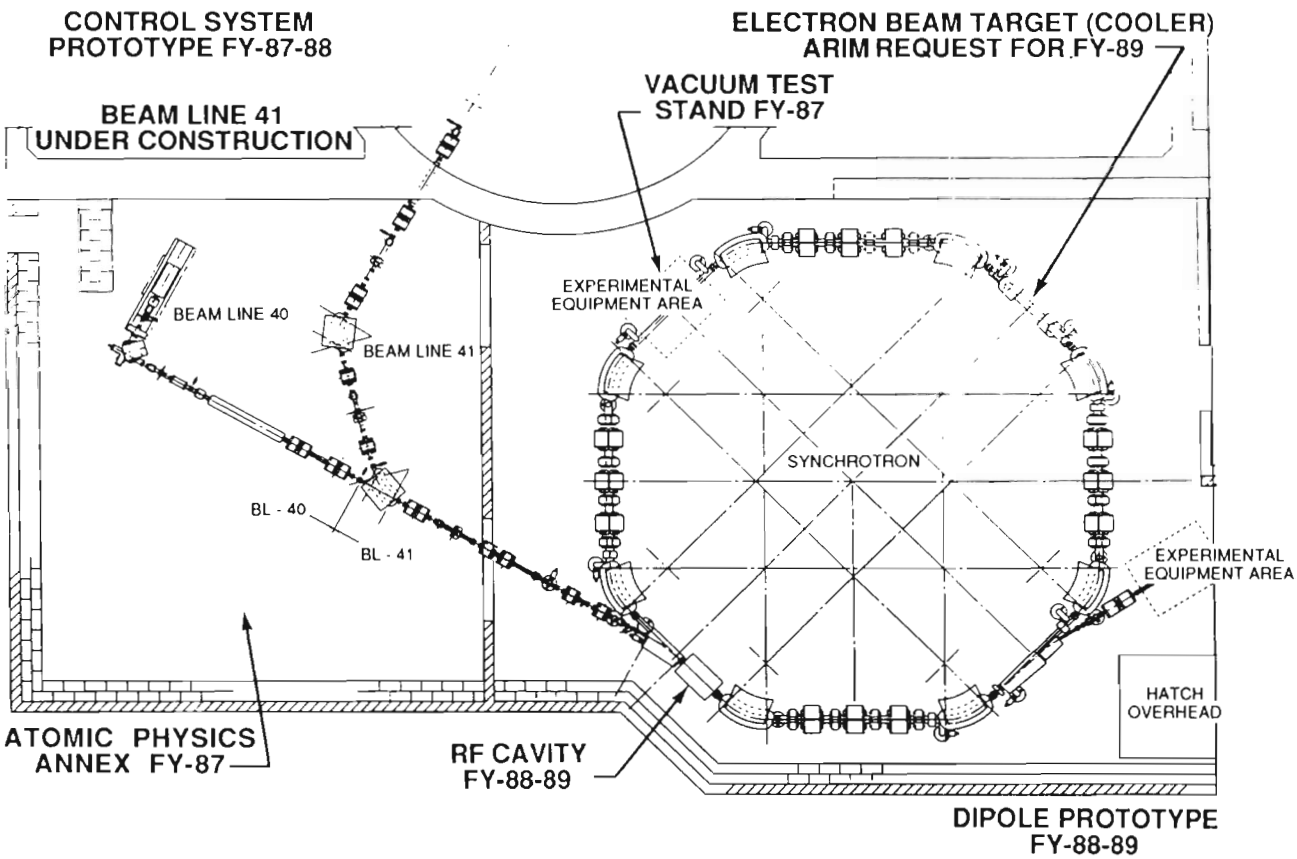


Fig. 6. Heavy-Ion Storage Ring for Atomic Physics.

vacuum ever attained west of the Atlantic—4 × 10^{-12} torr. A prototype broadband, ferrite-loaded rf cavity was designed and fabricated with assembly scheduled early in FY 1989. A magnet measurement system was developed, and a prototype laminated synchrotron magnet was designed and fabricated. Assembly and testing are under way. Prototype diagnostic devices are being fabricated and tested with pulsed heavy-ion beams, and a prototype system to control these synchrotron subsystems will be developed and purchased. In FY 1989 to 1991, $720 thousand funding is expected for development of an electron target for the HHIRF facility that is identical to that planned for the HISTRAP. Construction of the HISTRAP is requested for FY 1990 with a cost estimated at about $15 million (Table 8).

Table 8. Line-item construction budget by fiscal year for HISTRAP

($ in millions)

1990	1991	1992	1993
1.6	6.9	3.3	3.1

Advanced Processing Science Center

One of the central issues in the United States today is the erosion of U.S. global competitiveness in high-technology goods. As a new study by the National Research Council [materials science and engineering (MS&E) study] will show, improved materials synthesis and processing are central to the solution of this problem. This study also suggests that enhanced cooperation between national laboratories and U.S. industry could have an immediate effect on U.S. competitiveness. The need for developing advanced processing techniques has been recognized in several U.S. technology assessments including the MS&E study and the National Materials Advisory Board, Defense Advanced Research Project Agency (DARPA) Materials Research Council, Defense Science Board, Industry (SIA), and National Society (IEEE) surveys. ORNL has been a world leader in developing materials-processing techniques since the early 1940s. The focus of recent efforts has been on the development of advanced processing techniques capable of producing new materials properties and systems. Some of the recently developed ion-beam-, laser-, and plasma-processing techniques at ORNL are uniquely important for future electronic and opto-electronic device processing and for fabricating artificially structured materials for use in numerous other fields. ORNL has proposed to consolidate these R&D activities into an Advanced Processing Science Center (APSC) consortium with U.S. industry (Fig. 7). The goals of APSC are to develop and understand new processing techniques, to provide access to these techniques through our established user facilities, and to interact with U.S. industries through the consortium to commercialize R&D. This approach is being pursued through interactions with the DOE, the U.S. Department of Defense (DOD), Semiconductor Manufacturing Technologies (SEMATECH), Semiconductor Research Corporation, and other national laboratories.

Existing user facilities and collaborative research centers would form the nucleus of APSC and permit immediate start-up for industry to participate in and benefit from state-of-the-art R&D without a major investment in equipment or personnel. APSC and ORNL experience in technology transfer could be used to create a forum whereby competing industries could share technology and intellectual property while still competing in device and systems manufacturing. Participation by industry would ensure relevance between R&D and technology applications.

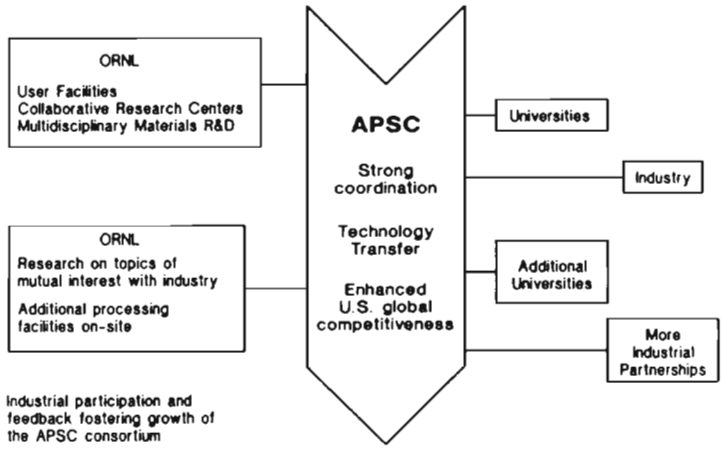


Fig. 7. Methodology for establishing an APSC consortium (immediate start-up using existing facilities and collaborations).

ORNL has already initiated several successful projects with the semiconductor industry:

- microwave plasma processing, IBM;
- laser photochemical vapor deposition, Dow Chemical;
- ion-beam deposition, Motorola;
- high-energy ion implantation, Eaton and Motorola; and
- thin-film deposition and mask development, Motorola, University of Wisconsin, and SEMATECH.

Semiconductor R&D at ORNL received about $2.9 million in FY 1987, and this amount increased to about $3.4 million in FY 1988. A similar increase to about $3.8 million is expected in FY 1989. Although the current activities lack the benefit of consolidation, the research is currently conducted in collaboration with more than 50 scientists from industries and universities. The estimated level of ORNL involvement in this program may reach $10 million to 12 million per year to support the full-time equivalent (FTE) of about 25 in-house staff members and 25 U.S. industrial/academic collaborators. Additional laboratory facilities may be required, costing about $10 million (Table 9). Extensions of these collaborations to other technologies are planned.

Table 9. Budget estimates by fiscal year for establishing an Advanced Processing Science Center

(includes new and redirected funds; $ in thousands)

Fiscal year	1988	1989	1990	1991	1992	1993	1994
Research and Development	3,400	3,800	5,000	7,000	10,000	10,000	12,000
Laboratory Facilities	0	0	2,000	3,000	3,000	2,000	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 Control 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 (AI) 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 ACTO 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 10).

Table 10. Budget projections by fiscal year for ACTO

($ in thousands)

1989	1990	1991	1992	1993
3670	5500	5000	5000	5000

Global Environmental Sciences

As a result of current concerns over global warming (i.e., the "greenhouse effect"), 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 proposed Center for Global Environmental Studies would be organized around five major themes, including a central focus of Global Systems Analysis, supported by research and analysis in Data and Model Systems,

Measurement Science and Instrumentation, Policy Analysis and Human Systems, and Large-Scale Environmental Studies. The proposed Center would be housed in ORNL's Environmental Sciences Division (ESD) and would involve numerous staff members from other ORNL divisions and collaborating universities. The proposed Center would serve as 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 provides technical and administrative leadership for the Office of Energy Research's (OER's) Carbon Dioxide Research Division (CDRD) for carbon-cycling research and is actively involved in assisting the Office of Health and Environmental Research (OHER) in relating its ecological process research on the DOE Environmental Research Parks to global environmental issues. The initial thrust of this assistance is the development of the OHER initiative "Terrestrial Biosphere Response to Large-Scale Environmental Change," which forms the basis for using ecological theory, mathematical modeling, and empirical studies on the parks in addressing regional- and global-level issues. The Laboratory's Energy Division is supporting the Office of Environment, Health, and Safety's (EH&S's) Office of Environmental Analysis (OEA) in developing policy options for mitigating global warming. Additionally, both Energy Division and ESD are assisting the Agency for International Development (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 to a national 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 analysis.

This initiative builds upon research currently supported at ORNL 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. Refer to Table 11 for budget projections.

Table 11. Budget projections by fiscal year for Global Environmental Sciences[a]

($ in millions)

1989	1990	1991	1992
5.0	6.0	7.5	9.5

[a]Includes university subcontracts but not capital equipment requirements.

Scientific and Technical Programs

Department of Energy

Office of Energy Research

The Oak Ridge National Laboratory's (ORNL'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 (OER), the largest single sponsor of research at ORNL (Table 12).

Table 12. 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]	54.15	47.91	59.79	61.96
HA02	Biological and Environmental Research	24.41	25.88	26.50	28.50
KA	High-Energy Physics	0.48	0.68	0.80	0.67
KB	Nuclear Physics	14.58	14.83	16.52	16.37
KC	Basic Energy Sciences	71.40	78.20	93.41	105.21
KD	Energy Research and Analysis	1.08	1.08	0.79	0.78
KE	University Research Support	0.44	1.20	1.30	1.30
KG	MEL-Facilities Support	35.80	33.97	37.81	40.07
Total		202.33	203.73	236.90	254.86
Percentage of total Laboratory funding—BA		42.4	42.4	40.9	40.1

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

[b]Note that the AT-Magnetic Fusion projections include the following levels of landlord General Plant Projects and Equipment funding:

	1988	1989	1990	1991
AT—General Plant Projects and Equipment (included in figures above)	11.00	10.40	19.80	20.80

AT—Magnetic Fusion

The Fusion Program at ORNL is a major component of the Office of Fusion Energy's (OFE) 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 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 and also has the potential for a substantially reduced environmental impact when 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 areas: Applied Plasma Physics (AT05), which funds theory, atomic physics, and diagnostic development; Confinement (AT10), which funds 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;

- effect 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 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, most notably the Culham Laboratory of the United Kingdom Atomic Energy Authority (UKAEA). Major collaboration will continue with the world stellarator program to develop key future experiments in Japan, Europe, and the Union of Soviet Socialist Republics (U.S.S.R.). 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 3 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 (Fig. 8), which started operating in 1988. 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 has (1) the flexibility to study various magnetic configurations and to provide a very important beginning to the understanding of toroidal confinement and (2) the potential for making definitive tests of the high-beta, second regime of stability, which promises improved performance for tokamaks and stellarators and 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 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 are used as targets for neutral beam and ion cyclotron heating. Central betas up to 1.5% have been achieved with 1 MW of neutral injection heating. A problem with magnetic field errors arising from nonsymmetries in the coil current leads is being corrected. This correction and the use of higher powers should improve performance in 1989.

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 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.

The D&T subprogram at ORNL continues to make impressive contributions throughout the breadth of its work. With the completion of the *Summary Report for the Large Coil Program (LCP)*, the Magnetics and Superconductivity Section personnel have returned to long-term

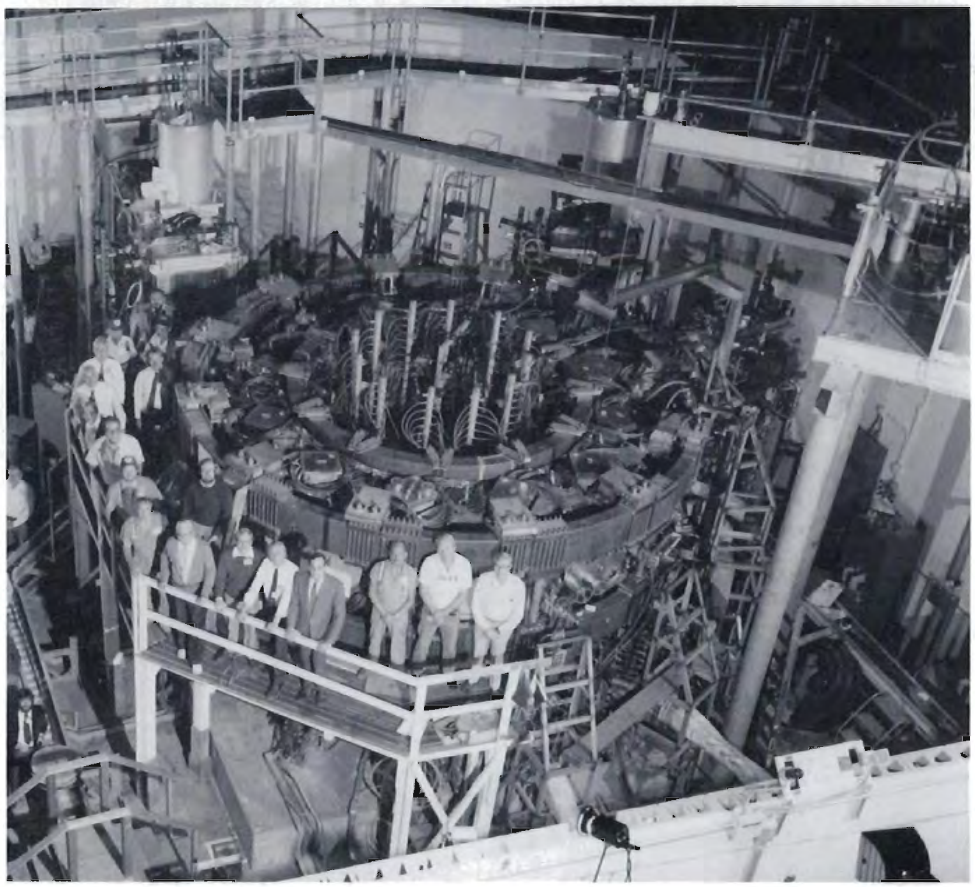


Fig. 8. The Advanced Toroidal Facility.

conductor development, exploiting the LCP experience in support of ITER and superconducting stellarators.

Some magnet design work will be provided in support of the ARIES project and experimental expertise will be contributed to selection of the insulation scheme for the Compact Ignition Tokamak (CIT) project.

Under the work for others, the Magnetics and Superconductivity Section will continue to support the Strategic Defense Initiative–Electric Power Research Institute (SDI-EPRI) effort on superconducting magnetic energy storage.

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. ORNL scientists will participate in rf heating experiments on these machines. ORNL is responsible for the CIT rf heating system (Fig. 9) and is building an antenna system for Alcator C-Mod at the Massachusetts Institute of Technology (MIT) that will be prototypical of the CIT system. State-of-the-art rf components developed at ORNL are being used at many experiments worldwide, in addition to the major systems described above.

The future efficacy of the magnetic fusion process as a contributor to energy needs is largely dependent on its prospects to become a continuous or steady state process. The country's mainline fusion system approach is the tokamak, which

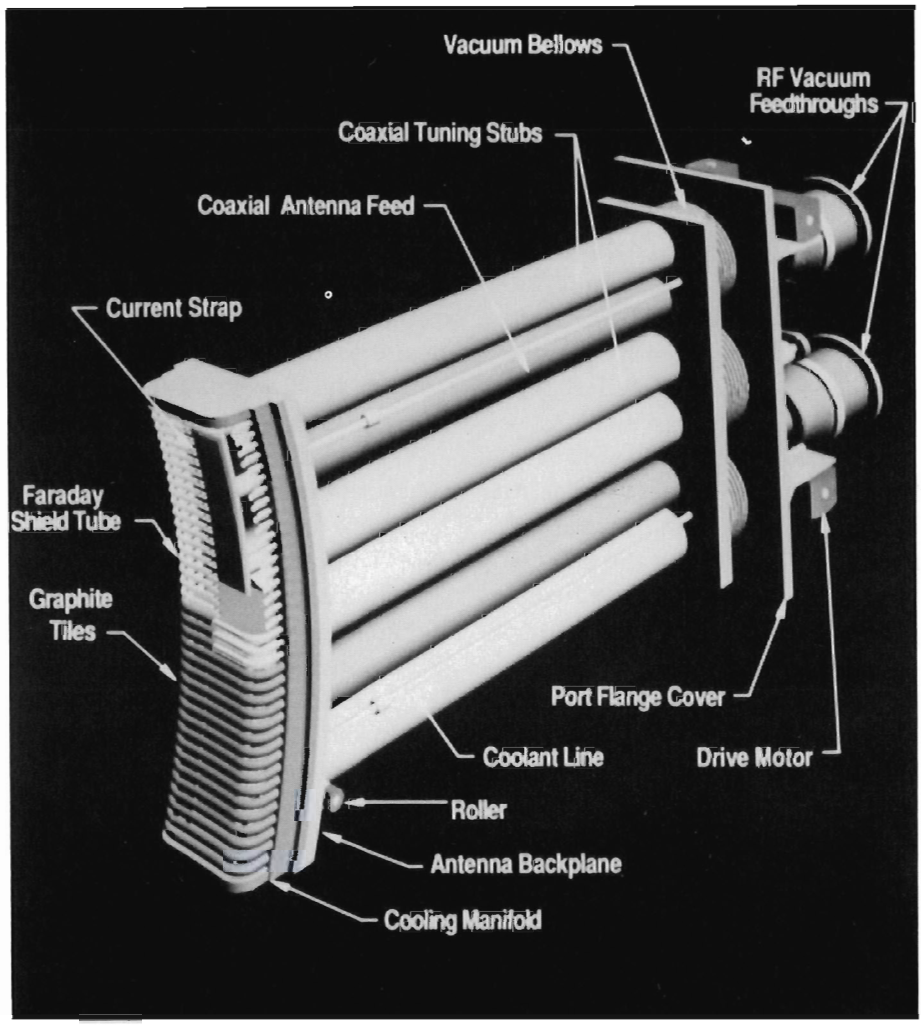


Fig. 9. CIT ion cyclotron resonance heating antenna.

requires noninductive methods of plasma current drive for continuous burning. ORNL is leading efforts to establish the viability of two such approaches: one using variations and advances in the application and technology for the rf developments and, second, applying high-energy (1- to 2-MeV) neutral beams that are accelerated by rf means.

The principal long-term method of fueling plasmas is by the injection of high-speed (>2000 m/s) pellets of solid hydrogen. The 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, a French project. 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 2 to 3 improvement in confinement time was seen. A factor of 4 improvement in the fusion reaction rate was also reported. Tritium pellet injectors are being developed to meet the needs of the CIT. Concepts are being studied for alternative fueling schemes, while advanced concepts are under development for producing significantly higher-velocity pellets.

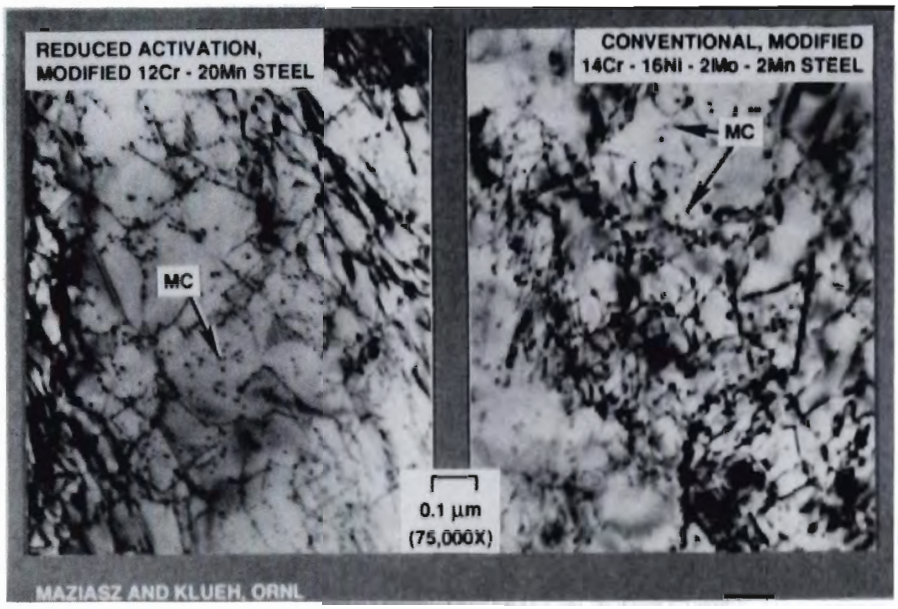
It takes many years to develop a production capability for radically new materials, and in anticipation of fusion's needs, such development has been under way at ORNL since the 1970s. Substantial advances have been made in the theory and development of steels to withstand the fusion neutron environment. 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 [Fig. 10(*a*) and (*b*)]. Some of these alloys will be tested in the newly upgraded High Flux Isotope Reactor (HFIR). 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, 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 (UCLA).

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.

(a)



(b)

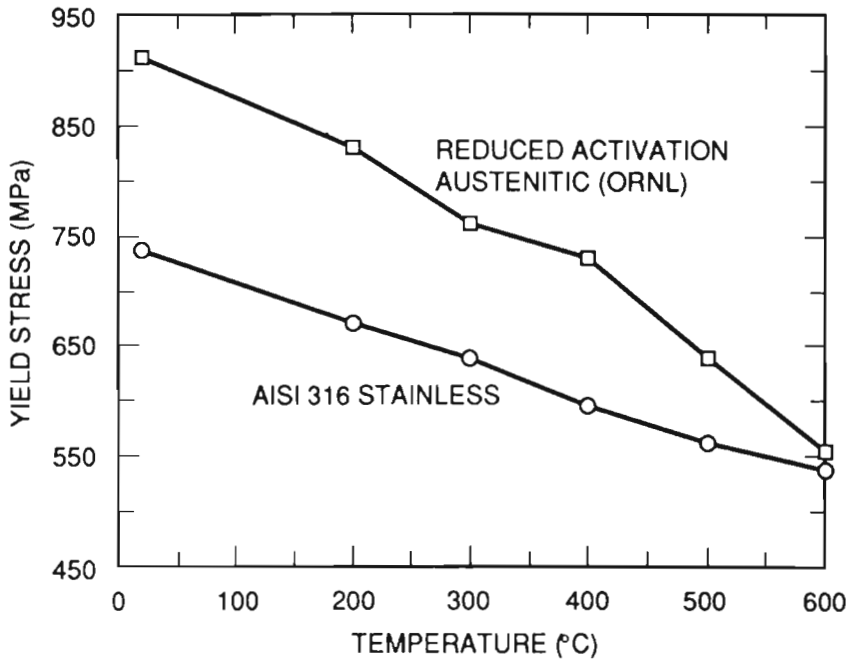


Fig. 10. (*a*) Reduced activation steel and AISI 316 develop similar microstructures in thermal stability tests at 800°C. (*b*) The yield strength of the reduced activation steel exceeds that of AISI 316.

- 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.

HA02—Biological and Environmental Research

Goals of the HA02 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.

Research areas in biology include mammalian genetics, molecular genetics, protein engineering, carcinogenesis, radiation biology, 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 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 HA02 Program: the Health Physics Research Reactor (HPRR), the Oak Ridge 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 HA02 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 HA02 program at ORNL is expected to experience growth in global sciences, subsurface transport studies, and radon-related research in this planning cycle.

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.

Within mammalian genetics, increasing reliance will be placed on molecular techniques for chromosome mapping and for characterization of mutations. To analyze mutant mouse stocks arising from exposure to chemicals or radiation, transgenic mice will be produced by microinjection of foreign deoxyribonucleic acid (DNA) into fertilized ova.

The mutant loci of transgenic mice, as a consequence of tagging with exogenous DNA, can be readily cloned and identified. Finely structured functional maps of radiation-induced deletion mutations will be generated by new techniques of in vivo saturation mutagenesis. Parallel mapping of selected parts of the mouse genome with restriction enzymes, together with information on conserved gene linkages between mouse and man, will facilitate structural studies of the entire human genome. 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.

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 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.

Gene products under close scrutiny include ribulose bisphosphate carboxylase (a determinant of biomass yield), epidermal growth factor (a polypeptide intimately involved in cellular growth and differentiation), enzymes involved in transcription of DNA, enzymes involved in the repair of chemically damaged DNA, and membrane transport proteins responsive to environmental insults.

Protein engineering (site-directed mutagenesis), an emerging program that is unique among DOE laboratories, integrates many activities in molecular genetics and biochemistry. The ability to program specific mutations into cloned genes will permit (1) the systematic design of new gene products as mechanistic probes of protein function and (2) the tailoring of operons to alter the regulation of gene expression. Molecular modeling with three-dimensional computer graphics will guide the selection of mutant gene products to be constructed and will serve as a predictive tool of the probable structural consequences. Because protein engineering provides an avenue for optimizing functional properties of enzymes, it may ultimately find broad application in bioprocessing.

Special attention will be given to site-directed mutagenesis of a methyltransferase that repairs potentially mutagenic lesions in DNA caused by alkylating agent. This protein is especially intriguing because, in contrast to enzymes, it is required in stoichiometric amounts; furthermore, its unusual stability presents a rare opportunity for studying protein folding.

Site-directed mutagenesis will also be used to establish structure-function relationships of epidermal growth factor (EGF), a small polypeptide ubiquitous in mammals that controls cell growth and differentiation. Current studies have identified amino acids in loops B and C that are necessary for recognition of cellular receptors (Fig. 11). Preliminary indications suggest that certain amino acid substitutions produce antagonists of EGF that may prove to inhibit growth of tumor cells.

Cancer studies continue to combine the

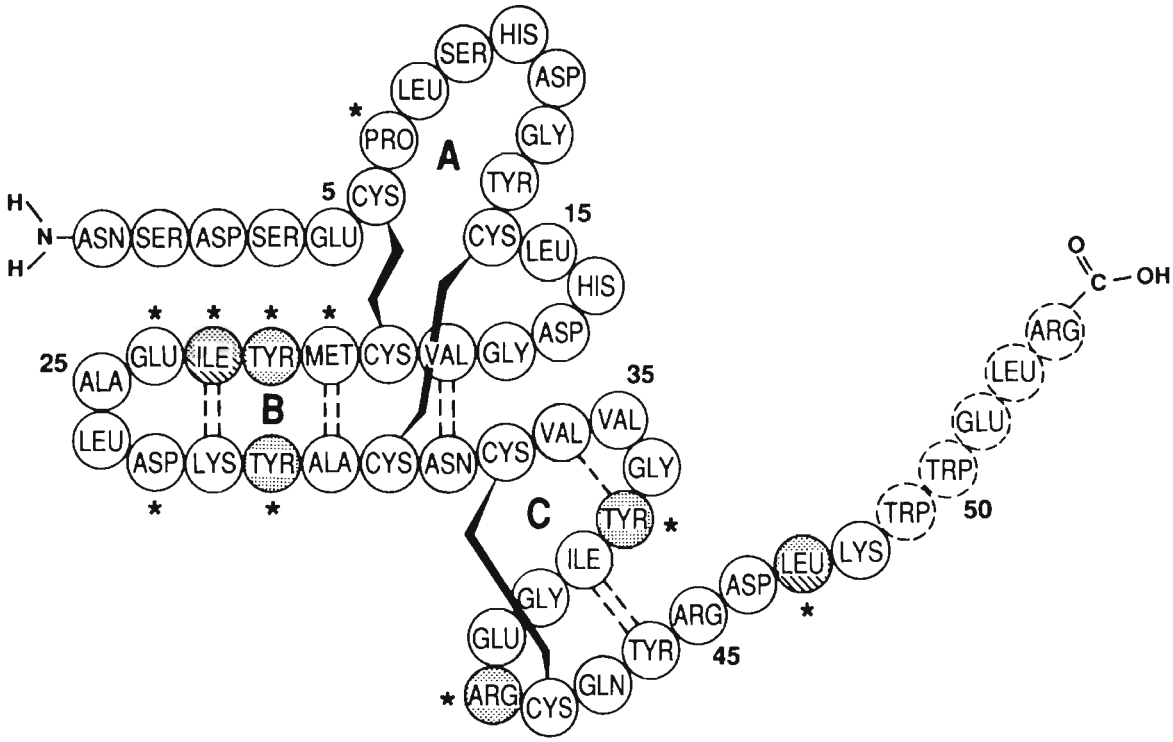


Fig. 11. The amino acid sequence and conformation of human epidermal growth factor. Amino acids at positions 49–53 are enclosed in broken circles to indicate conformational disorder in contrast to the highly structured regions of loops, A, B, and C. Asterisks denote amino acids that have been systematically replaced by site-directed mutagenesis. ORNL studies have shown that residues illustrated in a dot pattern are crucial to recognition of cell-surface receptors and that replacement of those residues illustrated in a diagonal-line pattern may produce inhibitors of cell proliferation.

investigations that elucidate mechanisms with those aimed at the practical problem of risk estimates, especially for high linear-energy-transfer (LET) radiation. 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.

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 the Office of Health and Environmental Research (OHER), has reoriented and integrated existing OHER 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 (Fig. 12). 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. We will continue our work in the areas of hydrology, geochemistry, and colloid chemistry in support of DOE programs in site-directed

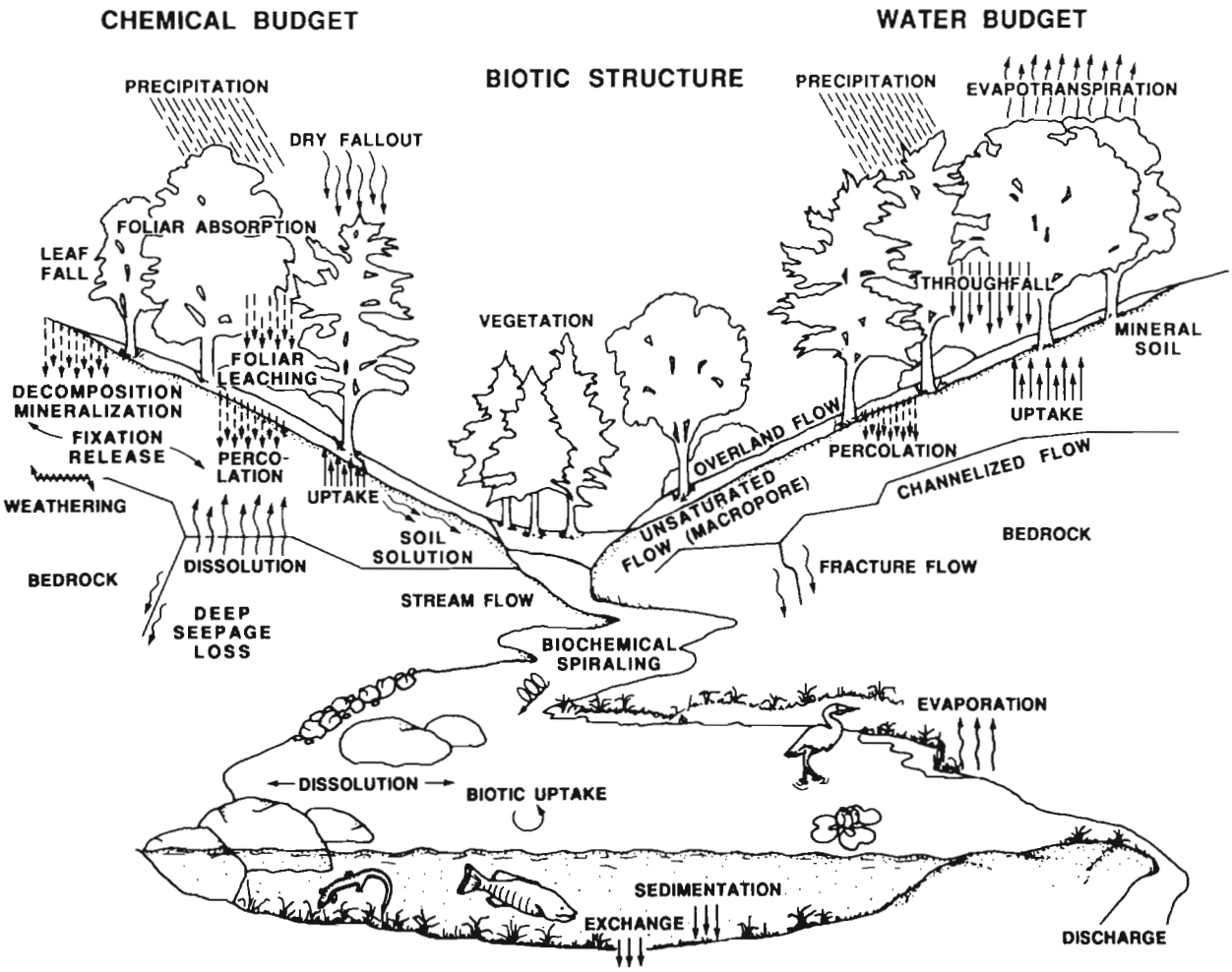


Fig. 12. ORNL's Walker Branch Watershed Project is entering the twentieth year of research and is focusing on linkages between biotic and abiotic systems.

subsurface transport of hazardous substances and subsurface microbiology. A new initiative on characterizing groundwater contaminant sources and transport and related monitoring strategies is planned (Fig. 13). Research efforts will increase on quantification of regional landscape patterns and the processes affecting ecosystems at large spatial scales.

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 serve as the foundation for the proposed ORNL Center for Global Environmental Studies, which would be housed in the Environmental Sciences Division (ESD) and involve 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 attendant 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 serves as an important research center for OHER in global carbon-cycle modeling and the study of CO_2 effects on vegetation. In addition, ORNL continues to provide support for the DOE's Carbon Dioxide Research Division (CDRD) through program planning, evaluation, and management.

The scientific goals of the Walker Branch Watershed Project directly coincide with the type of research identified by OHER as being a critical national research and development (R&D) need. In particular, one of OHER's missions is to understand the physical, chemical, biological, and geological processes that directly and indirectly control the flux of energy-related contaminants from their sources, through the environment, to sensitive receptors or long-term sinks. The research focus is on the spatial and temporal variations in mechanisms that regulate the storage, transformation, and transport of critical ecosystem resources such as carbon, nitrogen, and phosphorus. This focus is appropriate because the storage, transformation, and transport of most toxic trace metals and organic contaminants are physically, chemically, and biologically 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.

A new program area in Resource Analysis is being managed by the Carbon Dioxide Information Analysis and Research Program (CDIARP) in ORNL's ESD to support the studies that DOE's CDRD is conducting to analyze the measures that society might take in response to the effects of increasing atmospheric carbon dioxide and changing climate on natural and societal resources. The major tasks managed by CDIARP include (1) recommendations for the optimal definition(s) of regions to be used in regional-scale studies of the effects of changing CO_2-climate; (2) collection and quality assurance of data bases to be used in these studies; and (3) ranking of the relative importance of the various resources within the study region(s), based on such variables as economic measures, employment, land use, and sensitivity to changing CO_2 climate.

The main objective of the Global Carbon Cycle Research Program is to develop a scientific basis

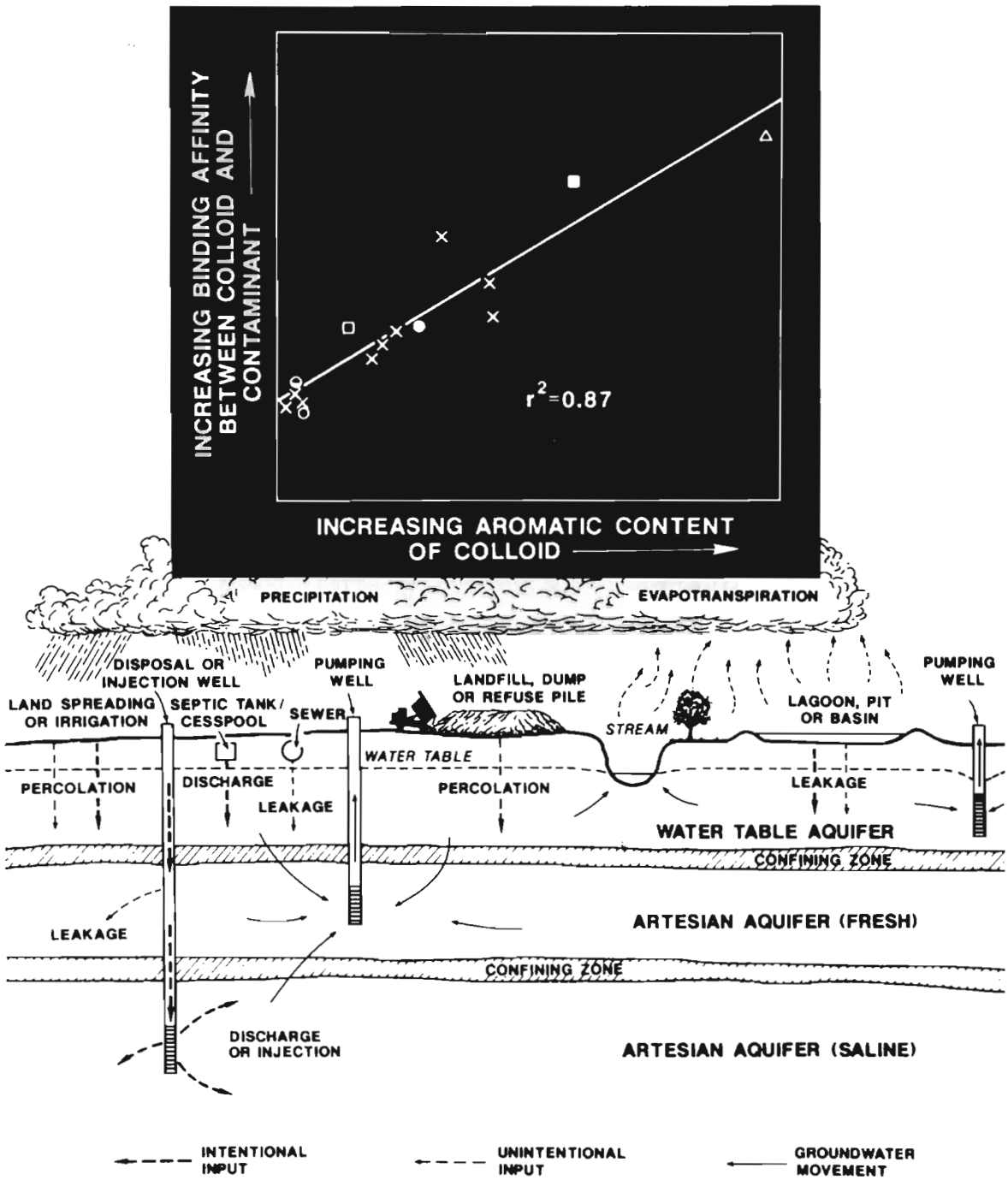


Fig. 13. Subsurface transport of organic contaminants is part of ORNL's support for DOE's site-directed subsurface initiative.

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. A major activity will be an increased role in coordinating program planning and research integration among CDRD contractors involved in global carbon cycle research. Integration of the research 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 (CDIAC) is to compile, evaluate, and distribute CO_2-related information in support of CDRD. In the coming years, CDIAC's research activities will reflect the new programmatic directions of CDRD. One area of emphasis will be on computer systems development for compiling, analyzing, and handling data and other information. CDIAC's activities will include research in all aspects of the CO_2 issue and technical management aspects of the national CO_2 program.

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 studies of chemical, biological, and physical agents associated with energy technologies; studies 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 and ensuring that an adequate technical capability exists to characterize and quantitatively measure such agents under various circumstances.

In this program, structures and properties of materials of biological or environmental importance, physical and chemical mechanisms that govern transport and chemical transformations of pollutants in the atmosphere-hydrosphere-biosphere, 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 on solid surfaces; in solids, liquids, and gases; 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. 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 the kinetics of radiation-induced reactive radicals and ions under controlled ambient conditions. 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 that 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 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 of broad national and international interest in using this well-characterized radiation source to conduct precise dosimetric studies using the HPRR, the proportion of HA-related research has been diminishing. Additionally, the HPRR has had greater availability to these scientists since it has become an ORNL user facility. The Dosimetry Applications Research Group expects to continue to use this facility for accident dosimetry and international intercomparison studies. This OHER-sponsored research represents only a small fraction of the HPRR usage. The programmatic responsibility for the operation of HPRR will be assumed by the major users of this facility.

The HPRR was shut down in March 1987; however, it is expected to reopen during FY 1989. Modifications to the HPRR are an ongoing activity. Administrative oversight of the HPRR will 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 commitment. This is a long-term trend, and it is appropriate for OHER to give up its oversight responsibilities, but to remain committed to continuous, long-term low-level use of this facility.

Construction of the Radiation Calibration Laboratory (RADCAL) was completed. RADCAL will be completely outfitted with a variety of beta, gamma, neutron, and X-ray radiation sources during FY 1989, with subsequent dedication of the facility and readiness for operational usage. The purpose of this facility is to perform personnel and radiation dosimetry research, perform dosimeter intercomparison studies, and 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 of RADCAL are shown in Table 13.

Table 13. Budget projections by fiscal year for RADCAL

($ in thousands)

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

Radon research remains a strong component of ORNL's multiagency-sponsored Indoor Radon Program. Basic research into the identification of the source of radon gas in the subterranean environment, transport of radon into structures, and cost effectiveness of mitigation techniques are areas of investigation. The ultimate purpose of this project is to better understand radon transport and factors that influence this transport into buildings where humans are exposed. Mitigation techniques may then be designed to effectively reduce these exposures.

A continuation of a 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 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. Once a new technique shows promise, further clinical evaluation is conducted through our extramural Medical Cooperatives Program 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 will be the restart of the HFIR and the future availability of the Advanced Neutron Source (ANS).

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 (ICRP), the National Council on Radiation Protection and Measurements (NCRPM), and the Medical Internal Radiation Dose (MIRD) 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.

A major goal of HASRD is to develop new methods and instruments to improve the ability to measure biomedical parameters of importance, especially biomarkers of exposure to or potential dose from toxic agents. Close coupling of biochemists and spectroscopists has led to numerous successes. Continued research on new and promising techniques such as surface-enhanced Raman scattering (SERS) is expected.

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.

Program Construction A chronic and critical problem requiring immediate, mandatory resolution is the aging of the energy-inefficient facilities currently used by the Biology Division at the Y-12 Plant site. The 45-year-old facilities were hurriedly constructed during the Manhattan Engineering Project for uranium processing and have been remodeled numerous times. The buildings have marginal service and utility capacities. The cost of utilities has risen more rapidly than other research-related costs, consuming about 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. Thus, in FY 1987, ORNL and the Biology Division began an interim program of reducing costs by eliminating facilities and consolidating research activities. It is quite clear that the long-term solution is the construction of new facilities, designed for biological research, at ORNL.

Conceptual design has been completed for a new facility to be located in the Life Sciences Complex at ORNL. The Molecular Genetics Laboratory will provide the modern and cost-effective facilities required to revitalize and expand research in the rapidly blossoming field of molecular genetics. The total estimated cost of the project is $10.1 million. Design is scheduled to begin during the first quarter of FY 1991, with construction starting in the second quarter of FY 1992 (Table 14). The long-range plan is to move the entire Biology Division from the Y-12 Plant to new modern facilities in the Life Sciences Complex at ORNL. Success in achieving these goals is urgent and will require negotiations among ORNL, Oak Ridge Operations (ORO), and DOE. It is imperative that these plans proceed in a timely fashion.

Because DOE/OHER's established genetics research program investigates the genetic effects of energy-related chemicals, it is essential that we have new laboratory and animal space designed specifically to enable personnel to handle hazardous chemicals safely. The air supply system upgrade is essential for achieving a higher number of air exchanges per hour in the experimental animal quarters in the Biology Division, thus preserving a unique resource among DOE contractors (Table 14).

There are obvious programmatic advantages to relocating the Biology Division from the Y-12 Plant to the existing Life Sciences Complex at ORNL. Other biomedical and environmental sciences divisions are located in the Life Sciences Complex, and they provide an opportunity to share resources and to enhance collaborative research efforts. Many essential facilities are located at ORNL, including the National Center for Small-Angle Scattering Research (NCSASR) and the BRF. In addition, a major problem of security access can be eliminated because it will probably become more difficult for noncitizens to enter the Oak Ridge Y-12 Plant. Minimum security would be needed at ORNL's west end where the Life Sciences Complex is located.

Table 14. HA02—Construction summary

($ in millions)

	Fiscal year			Total estimated cost
	1991	1992	1993	
Upgrade air supply system, Bldg. 9210, part I	0.4	2.6		3.0
Upgrade air supply system, Bldg. 9210, part II		0.3	3.7	4.0
Molecular Genetics Laboratory	1.1	9.0		10.1
Total	1.5	11.9	3.7	17.1

KA—High-Energy Physics

The High-Energy Physics Program is small but anticipates some growth related to the national Superconducting Super Collider (SSC) project. Some activity in transport and cross-section calculations for the SSC is expected in addition to ongoing radiation-shielding design studies. Another source of increased funding is the assignment of a superconducting magnet specialist to provide technical assistance to the Superconducting Super Collider Division. Ongoing activities also include one ORNL staff member for The University of Tennessee, Knoxville (UTK)-based ORNL-UT Collaborative Program for the experimental study of the properties and interaction characteristics of elementary particles.

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 thousand) 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. The most heavily used new equipment will likely be 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.

Another major new addition will be the Recoil Mass Separator (RMS), a $2.2-million device jointly sponsored by ORNL, Idaho National Engineering Laboratory (INEL), and a number of universities. This apparatus will be designed and assembled early in the period with initial operations planned for FY 1991. A total of $450 thousand is expected from DOE for the RMS with the balance of support from the state of Tennessee and the university sponsors.

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. A number of sodium iodide elements in the spin spectrometer will be replaced by Compton-suppressed elements with barium fluoride-bismuth germanate composite shields. This improvement will make possible higher-resolution studies of the nuclear processes at high spin and temperature.

ORNL staff members will also be involved in a proposed national 4π gamma-ray detection facility, the Gammasphere, estimated to cost about

$16 million for capital equipment and up to an additional $3 million for site preparation and installation. The HHIRF is one of the sites in contention for this device. Because of existing facilities at the HHIRF, the cost for site preparation and installation would decrease to about $700 thousand.

Computing facilities will be upgraded with the development of an Advanced Computer Project (ACP) multimicroprocessor system initially intended for processing of the volumes of magnetic data tapes generated in experiment WA80 at the Conseil Europeén pour la Recherche Nucléaire (CERN).

KB03—Nuclear Theory Program Major thrusts of the Nuclear Theory Program are mean field (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 a UT-ORNL 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 an Institute for Computational Physics (ICP) has been proposed that would request joint funding from the state of Tennessee and DOE. The objectives for this ICP are similar to the ORNL initiative described previously—Center for Computer Enhanced Scientific Productivity—except that the ICP plans to concentrate on scientific problems in the fields of nuclear, particle, and atomic physics.

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 and computer code development, neutron scattering, and gamma ray spectroscopy. New initiatives at ORELA for the reporting period include a complete upgrade of the rf drive system and replacement of the existing data acquisition computer system. 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, and a study of collective nuclear motion using a variety of hadronic probes at a number of accelerator facilities in the United States and abroad. This giant resonance research is expected to place greater emphasis on collaborations at European heavy-ion facilities that offer higher beam energies than the HHIRF.

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 HFIR and the Bulk Shielding Reactor (BSR), development of the ANS (see "Continuing Initiatives"), and increased efficiency and effectiveness in user interactions. For planning purposes, we assume that the HFIR will restart in early FY 1989 and that the ANS will be a line-item project with design commencing in FY 1991. A construction summary and further details are given in Table 15 and in the "Continuing Initiatives" section.

KC02—Materials Sciences The Materials Sciences subprogram supports fundamental materials R&D; neutron scattering, ion beam, laser, and plasma processing; synthesis and

Table 15. KC—Construction summary

($ in thousands)

	Budget and reporting code	Project year	Fiscal year							Total estimated cost
			1988	1989	1990	1991	1992	1993	1994	
Advanced Neutron Source (ANS)	KC02	1991				9,500	10,000	14,600	39,512	412,000
ARIM-HFIR	KC03	1987								430
ARIM-Beam Lines for Atomic Physics, HHIRF	KC03	1987								300
AIM-HFIR	KC03	1989		720						720
AIM-Electron Target, HHIRF En Tandem	KC03	1990			720					720
Heavy Ion Storage Ring for Atomic Physics (HISTRAP)	KC03	1990			1,600	6,900	3,300	3,100		14,900
Safety Improvements, HFIR	KC03	1990			1,300	4,000	2,200			7,500
AIM-Multicharged Ion Research Facility	KC03	1990			480					480
Planning Period Total			0	720	4,100	20,400	15,500	17,700	39,512	437,050

characterization of new materials; high-temperature materials; ceramic processing; and theoretical studies for advanced energy-related materials. Materials Sciences also supports a number of user facilities. One of these user facilities, the Low Temperature Neutron Irradiation Facility (LTNIF), is located at the BSR. The United States will lose unique capabilities for materials characterization if the BSR is decommissioned, as is currently planned.

As an example of the emphasis given to materials science, three of the Laboratory's continuing initiatives are in this rapidly growing area (see "Continuing Initiatives"): the ANS, high-T_c superconductor R&D, and the Advanced Processing Sciences Center (APSC). Because of the magnitude of the ANS project, funding for the KC02 subprogram is largely expected to follow the progress of the ANS, increasing during the R&D phase of the preconceptual design, then falling off until the construction of the facility is under way. Funding for the core program tasks is expected to remain stable during the reporting period with some growth as described below.

Funding is expected to increase for research in 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. An effort will be made to provide a first-principles understanding of the complicated processes and interactions occurring at the surface of materials observed through field ion emission and scanning tunneling microscopy. Also, studies will continue using synchrotron radiation as both a scattering and spectroscopic probe to examine crystalline and amorphous solids. Growth is also anticipated in microstructural analysis with the use of high-resolution analytical electron microscopy including imaging, convergent-beam electron diffraction, electron-energy-loss spectroscopy, and energy-dispersive X-ray spectroscopy. A promising new technique is atom-probe field-ion microscopy that offers atomic-resolution imaging, high-resolution time-of-flight spectroscopy with single-atom sensitivity, and imaging atom-probe techniques. The unique capabilities of these microscopy techniques will be used to obtain new information on processes such as phase transformations, segregation, and deformation that involve microstructural change.

The radiation effects program develops mechanistic understanding of the processes by which ion-beam treatments and neutron irradiation alter physical and mechanical properties of metals and ceramics. The work is applied to exploiting new materials and properties made possible by ion-beam technology and to designing radiation-resistant metals and ceramics. This program will use the new, 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. Some of the work performed in this task, and in many other tasks within the Materials Sciences Program at ORNL, contribute to the successful design of the ANS.

In the area of engineering, materials funding is expected to be stable for the core program. This 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 to develop and understand a new process for preparing adherent ceramic coatings on metal and ceramic substrates by using ion beams to both decompose and control the composition of polymer precursors. The result of this study would be a new approach toward the

preparation of coatings for wear, corrosion, or thermal resistance based on an understanding of the chemical and physical processes involved.

Another significant research area is the chemistry of advanced inorganic materials. This area includes materials processing of whiskers (single-crystals) for use in composites and the development of new methods for synthesis of advanced (nonoxides) ceramic materials. One of the goals of this research is to develop advanced fiber-whisker-reinforced ceramic or metallic matrix composites.

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 has been made to upgrade instruments at the HFIR. New instruments to be installed at the HFIR include a high-resolution powder diffractometer and a triple-axis spectrometer. The topics studied using neutron scattering include condensed matter properties, defects, structure and dynamics of advanced polymeric materials, superconductors, and hydrides. Recent highlights include the determination of magnetic structures in high-critical-temperature superconductors, the kinetics of phase transitions in alloys, and the testing of a new theory of the thermodynamics of polymer mixing. The Materials Sciences Division also supports a neutron users program that successfully built a large user community for the HFIR. As neutrons become available once again, this program must restore and expand the user relationships previously developed. A new initiative related to neutron scattering is a program aimed at improving the effectiveness of research reactors by the design of imaginative new instrumentation, for example, an efficient transmission polarizer.

Another area expected to grow steadily is semiconductors. The semiconductor R&D program at ORNL emphasizes the development of new thin-film materials and processing technologies using state-of-the-art surface modification and characterization techniques. Facilities are available for ion implantation, ion-beam deposition, laser-photochemical-vapor deposition, laser and microwave processing, solar-cell fabrication, plasma processing (glow discharge, rf, ECR), neutron transmutation doping, 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, 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, fabrication of optical waveguides using ion implantation, development of ECR plasma processing for damage-free deposition and etching of submicron structures, mask development for X-ray lithography, and development of microwave sintering for ceramic processing (electronic packaging). The research involves silicon- and germanium-based materials (including oxides and silicides), III-V and II-Vi compounds, 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 Surface Modification and Characterization/Collaborative Research Center (SMAC/CRC).

A major thrust in the Materials Sciences at ORNL is high-T_c superconductor R&D (see "Continuing Initiatives"). This area is expected to grow rapidly with funding from several sources including the Office of Basic Energy Sciences (BES). The high-T_c superconductivity research effort at ORNL is multifaceted, containing both fundamental and applied research, applications

assessment, and cooperation and exchange with other national laboratories and with industry. ORNL has lead responsibility in coordinating research among the DMS-funded programs at ORNL, LANL, and LBL.

In the spring of 1988, ORNL was named one of three DOE Superconductivity Pilot Centers for transfer of high-T_c superconductor technology from the national laboratories to industry. The basic and applied research efforts include synthesis and characterization experiments using a wide variety of techniques and equipment spread over four technical divisions at ORNL. High T_c materials are prepared in powder, ceramic, ceramic wire, thin film, and single crystal forms. Magnetically oriented textured thick films are prepared using high-T_c powders of either $YBa_2Cu_3O_x$ or the rare-earth-substituted analogs. Thin films of Y "1-2-3"-based materials are prepared using laser ablation techniques, electron beam co-evaporation, molecular beam epitaxy, and thermal reactions.

Microwave sintering of sol-gel–derived ceramic superconductors is used to consolidate powders. High-T_c materials are characterized using Rutherford-backscattering and channeling methods; X-ray diffraction; transmission and scanning transmission electron microscopy; atom probe and Auger spectroscopy; magnetic, transport, thermodynamic, and kinetic properties measurements; neutron scattering; and phase behavior.

The major emphasis of the applied research is to develop methods for increasing the critical current limit by controlling the microstructural effects of stoichiometry on microstructure and grain boundary compositions and on the use of magnetic fields and other techniques to produce oriented-grain powders.

Theoretical research includes modeling of these new high-T_c systems and investigations of the theoretical aspects of the stability of high-T_c superconductors. Research toward the discovery of new high-T_c materials is also undertaken. In addition to the basic and applied research described above, ORNL has several applications assessment projects under way related to high-T_c superconducting materials (see "Conservation and Renewable Energy" section).

KC03—Chemical Sciences The Chemical Sciences subprogram supports the HFIR, the Transuranium Processing Plant (TPP), 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 "Continuing 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 1990.

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. ORNL plans to formally establish the ECR multicharged ion source as a

collaborative research facility. 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.

The atomic theory group will be enhanced by the addition of an ORNL-UT Distinguished Scientist. Areas of emphasis during the period 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.

Preparations for restart of the HFIR reactor have been intense over the more than 2 years of shutdown. It is hoped that the reactor will restart in early- to mid-FY 1989. Neutrons from the HFIR are vital to many research projects in the Material Sciences, Chemical Sciences, Magnetic Fusion, and Biological Sciences programs at ORNL and for users and collaborators from many universities, national laboratories, and industries in the United States and abroad. One of the prime purposes of the HFIR is to make research quantities of ^{252}Cf and other transuranium isotopes. The medical research community is one of the more vocal groups that support an HFIR restart because the inventory of ^{252}Cf is diminishing rapidly. A diverse number of neutron irradiation tests and experiments are performed at the HFIR as well as neutron diffraction experiments and operation of a small-angle neutron scattering facility sponsored by the NSF. Since 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.

Operating expenses for the HFIR after restart will be nearly double the preshutdown levels, including about a 50% increase in staff. These increases are necessitated by the revised operating conditions imposed by the restart.

The isotopes program is essential for production of both stable and radioactive isotopes used in medical applications and in basic research. As in the past, there has been some discussion of transferring responsibility for funding and administration of the isotopes program from KC03 to a different office within DOE. If approved and completed, this move would represent a significant change in the Chemical Sciences Program at ORNL. The transuranium element isotopes produced in the TPP are used nationally and internationally to study the basic physics and chemistry of the transuranium elements. They are also used in R&D programs relating to environmental effects, biological effects, and waste isolation. Extensive upgrades are planned for both the Isotopes Separation Facility and the TPP.

The most significant change anticipated in the chemistry program during the reporting period is the move of mass spectrometry equipment and personnel into a building that is currently under construction. This facility will house an Organic Chemistry Mass Spectrometry Laboratory (to be occupied during FY 1989) and an Inorganic Chemistry Mass Spectrometry Laboratory (to be occupied 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 equipment was housed at the Y-12 site.

ORNL continues to improve existing analytical techniques and to develop new ones. Some of the methods currently in use or 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 MS/MS, positron spectroscopy and heavy-ion-induced X-ray satellite emission.

Other areas in the chemistry program that expect some growth include basic aqueous chemistry at high temperatures and pressures. This research addresses thermodynamic properties of electrolytes and nonelectrolytes in addition to equilibrium and kinetic studies providing chemical properties in aqueous solutions. The systems studied are selected for their practical applicability in energy-related technologies and for their fundamental significance in steam generation, nuclear and chemical waste disposal, chemical processing, the extraction of heat and material resources, and basic hydrothermal geochemistry. New initiatives involve structural information on electrolytes at high temperatures and pressures studied using neutron and X-ray scattering.

Previous work in molecular research with electron spectroscopy will be reprogrammed and merged with research in heterogeneous catalysis related to energy systems. Some growth is expected in this area in addition to the combined funds. The merger results in a new initiative to use synchrotron radiation as a probe of electronic structure and dynamics in absorbed atoms and molecules. A previously small component of the synchrotron research, photoemission from molecules absorbed at surfaces, will now be emphasized. The heterogeneous catalysis work will also be expanded by an emphasis on catalytic processes on well-characterized surfaces that model the complex transition metal sulfides used in industry.

An area of continued emphasis will be obtaining new molecular-level knowledge concerning the organic chemical structure and reactivity of coals. 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. During FY 1989, research on the chemistry of aromatic compounds in molten-salt catalysts will change to a study of the photochemistry of aromatic compounds in water and sorbed on solids. Much of the spectroscopic methodology used on the molten salt program is applicable to the photochemistry aspect as well. 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.

KC04—Engineering and Geosciences The Engineering and Geosciences subprogram supports two efforts: the Center for Engineering Systems Advanced Research (CESAR) and Geochemistry. 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 a new robot, HERMIES-III (available in FY 1989), which will have human-scale manipulative capabilities. 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. One new engineering initiative is a proposed study of advanced bioprocessing systems for energy production and conservation. Several new initiatives have been proposed in the area of geochemistry, including one to study the nature of strike-parallel discontinuities within a thrust-faulted sedimentary terrain and a second to study the occurrence of methane in unconventional environments.

KC05—Advanced Energy Projects The Advanced Energy Projects subprogram funds an exploratory energy project to study methods of recovering cellulase from aqueous solutions. The study will be completed early in the reporting period. 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.

KC07—Applied Mathematical Sciences The Applied Mathematical Sciences subprogram supports research in parallel-processing algorithms and the development of applied mathematical and statistical methods for analyses of physical processes. These research activities will benefit from the recent upgrade of ORNL's Intel hypercube parallel computer that has yielded a factor-of-5 improvement in computing speed and data bandwidth.

A research area growing in emphasis is the design and analysis of computational experiments (DACE). In the fall of 1988, a workshop on DACE was hosted by ORNL and sponsored jointly by several agencies, including the DOE/BES Division of Applied Mathematical Sciences. The common element in this new area is the need to develop efficient strategies for the use of computationally intensive computer models. One of the new initiatives for ORNL discussed previously is the Center for Computer-Enhanced Scientific Productivity. The expertise developed in the Applied Mathematical Sciences Program will be one of the key foundations for developing this new initiative. Funding for this program is expected to increase significantly during the reporting period to support activities related to parallel processing and for an ORNL-UT Distinguished Scientist.

KD—Energy Research and Analysis

Energy Research and Analysis activities at ORNL provide technical assessments of DOE programs and evaluations of energy-related technologies to OER. The funding level in this activity is unpredictable because it is dictated by the needs of OER.

KE—University Research Support

The University Research Support program (KE) activities stimulate the involvement of the university community in ORNL research programs.

- In FY 1988, the University Laboratory Cooperative Program (ULCP) provided financial support to over 50 student and faculty research participants in a variety of disciplines.
- Twenty-nine undergraduate students and four faculty representing two consortia participated in the Oak Ridge Science Semester program, an academic-year program in its second decade that permits students to engage in research and take classes under the direction of resident faculty. The students then receive credit at their home institutions.
- The SERS Program, sponsored by DOE, and jointly managed by ORNL's Office of University Relations and Oak Ridge Associated Universities (ORAU), is now beginning its second year of operation supporting nearly

60 participants, including undergraduates, graduate students, and faculty for academic-year internship opportunities.

- The High School Honors Workshop under the technical leadership of ESD hosted 57 high school students for a 2-week period. Participating students represented each state, Puerto Rico, the District of Columbia, and several foreign countries. This program is expected to continue in FY 1989 and beyond.
- The ULCP also sponsors visits to ORNL by minority educational institution faculty to encourage potential collaborations at an increased level.
- Two areas of special emphasis in ULCP are to provide opportunities for participants from minority educational institutions and to expand precollege programs.
- In FY 1988, ULCP supported the summer appointments of 11 students and 3 faculty from historically black colleges and universities (HBCUs) and 7 students and 3 faculty from Hispanic institutions.
- The ULCP helped support the operation of the Ecological and Physical Science Study Center, a program for students in grades 1–12 that offers field-study modules in "hands-on" science activities. In FY 1988, over 4,000 students and teachers were served by the Study Center program, and demand continues to outstrip available resources even though the program now provides activities on a year-round basis.
- Under the national Residence in Science and Technology program (REST), costs for summer appointments for two high school teachers were supported.

Also sponsored by the KE program is the Industry Technology Exchange Research Program, which provides incremental expenses for the assignment of industrial researchers to ORNL. One researcher from IBM completed his assignments involving microplasma processing. Four nominations were submitted for FY 1989.

The KE program is expected to grow substantially in FY 1989 and beyond. Some of the growth will be the result of the SERS program, where 50 participants will be supported each semester. Growth is also expected in precollege education and efforts with minority educational institutions.

Although not currently sponsored directly by the KE program, ORNL initiated a number of new activities in support of precollege and minority program development in FY 1988. Several of these new initiatives are expected to be funded by the KE program next year. A summary of these initiatives is given in the "University Relations" section of this report.

An overall need to provide an environment conducive to these science activities is to provide a physical facility to house these expanding programs.

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 (Fig. 14). This funding category supports work of two types:

- activities necessary for providing ORNL the capability to be in compliance with environmental regulations and requirements with regard to ongoing waste management operations and environmental monitoring and
- remedial actions associated with inactive facilities resulting from past research, development, and waste management activities.

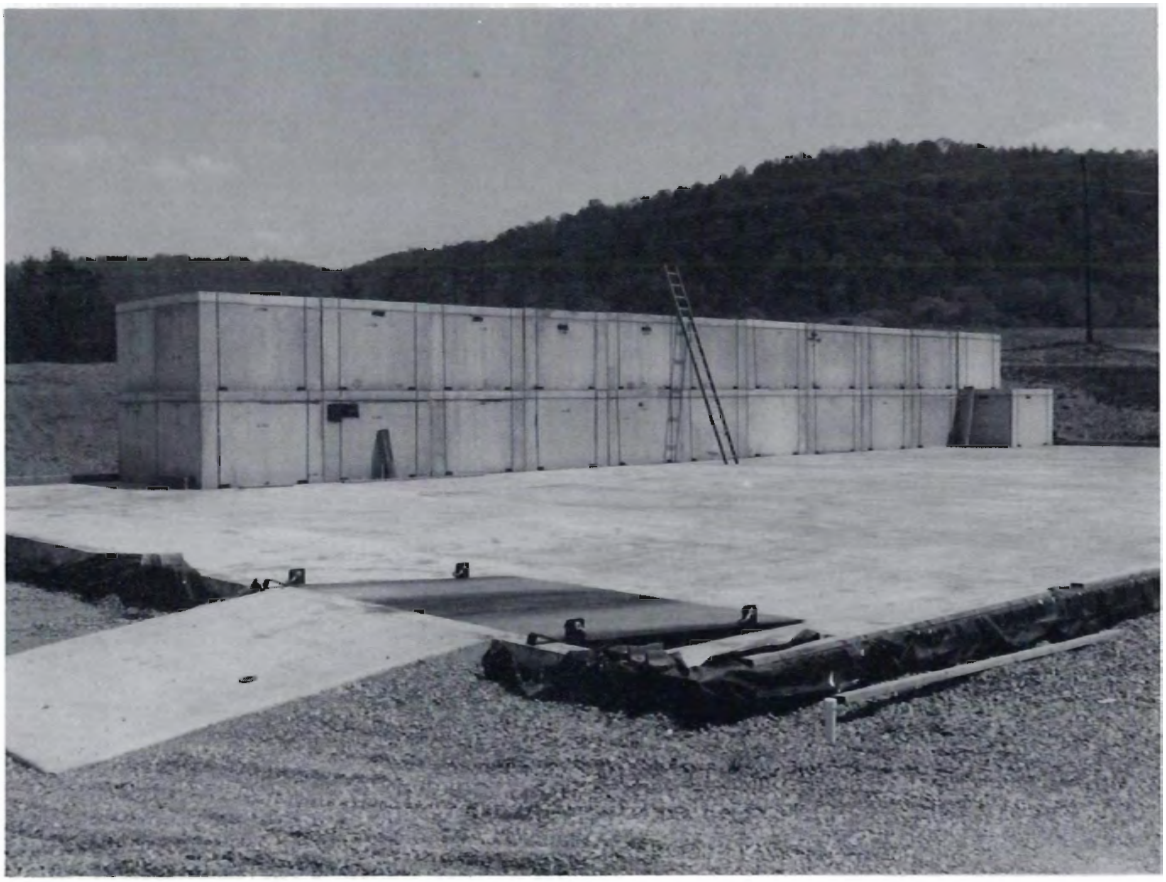


Fig. 14. A tumulus-based demonstration for providing greater confinement disposal of solid low-level waste is in progress at ORNL. Solid low-level waste is emplaced in concrete vaults, and the remaining void space is filled with cement. The stacked vaults will be covered subsequently, and releases from the tumulus will be monitored to evaluate performance.

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 to improve environmental monitoring capabilities for the site. Construction was completed during FY 1988 of six large tanks (Fig. 15) and an associated process wastewater collection system that will replace seven unlined impoundments as part of the $16.9 million Nonradiological Wastewater Treatment Plant line-item project. A treatment plant for removal of heavy metals and organic contaminants from process wastewater will be completed during FY 1989. Detail design is well under way 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

Fig. 15. These two 350,000-gal tanks and four additional 100,000-gal tanks are being constructed as part of the nonradiological Wastewater Treatment Plant line-item project. These tanks will replace the unlined ponds which are currently used for collection of process wastewater at ORNL.

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 (Table 16).

Assistant Secretary for Nuclear Energy

The Assistant Secretary for Nuclear Energy (ASNE) 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 17).

AF—Nuclear Energy R&D

Consolidated Fuel Reprocessing Program The Consolidated Fuel Reprocessing

Table 16. KG02—Construction summary

($ in thousands)

	Budget and reporting code	Project year	Fiscal year							Total estimated cost
			1988	1989	1990	1991	1992	1993	1994	
Non-Rad Wastewater Treatment Plant	KG02	1983	6,987							16,887
LLW System Upgrade, Bethel Valley	KG02	1988	4,800	11,700	13,300	5,200				35,000
Isotopes Area LLW CAT System Upgrade	KG02	1991				5,800	10,900	7,700	2,800	27,200
Melton Valley LLW CAT System Upgrade	KG02	1992					3,000	10,000	7,000	20,000
Decontamination Facility	KG02	1994							3,000	20,000
Subtotal			11,787	11,700	13,300	11,000	13,900	17,700	12,800	119,087
GPP				4,000	4,000	4,000	4,000	4,000	4,000	
Total				15,700	17,300	15,000	17,900	21,700	16,800	

Table 17. 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	33.23	34.17	33.69	35.87
AH	Remedial Actions and Waste Technology Programs	8.89	2.76	1.64	1.32
CD	Uranium Enrichment	0.42	0.3	0.3[b]	0.3[b]
Total		42.54	37.23	35.63	37.49
Percentage of total Laboratory funding—BA		8.9	7.8	6.2	5.5

[a]Figures include operating BA, capital equipment, and funded/budgeted construction if any.
[b]Funding for AVLIS, the largest CD program, will flow through the ORGDP Financial Plan beginning in FY 1988.

Program (CFRP) focuses primarily on a broad 5-year R&D collaboration with the Power Reactor and Nuclear Fuel Development Corporation (PNC) in Japan to support their effort to develop and demonstrate technology for reprocessing breeder fuels. This joint 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 program, and $5 million to $10 million in additional funds are to be provided by PNC for specific hardware. This effort is also expected to lead to additional procurement of engineering services and hardware in the United States. The benefits are complementary for both Japan and the United States: PNC is gaining access to much of the breeder reprocessing technology that the United States has chosen not to use in the near term while the United States expects to maintain the core of expertise 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 a broad range of 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 continuous head-end hardware systems for fuel element disassembly with lasers, shearing, and dissolution; and (3) overall support to facility concepts and design.

Minor technical exchanges continue in a comparison study of the fuel cycle facility concepts with the United Kingdom and in a rad-hardening of signal transmission systems with France. Both efforts will be concluded in FY 1989. A new program to get a "hot" demonstration of centrifugal contactors in UK's Dounreay fast breeder reprocessing facility is under way.

Activities continue to transfer the Advanced Servomanipulator (ASM) technology to industry and to seek broader use of centrifugal contactors in

other DOE facilities and industry for reprocessing and scrap recovery. Test contactor units have been built and provided to several DOE sites, and a production-type system is being installed at the Y-12 Plant.

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 developing and implementing 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. 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), 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; and (4) 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 energy generation in water-limited regions. The 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, reliability, 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 Control Test Operation (ACTO) 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 B_4C for LMR near-core and deep-sodium environments. 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. 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.

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 1989 and 1990 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 its production capability and 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 processing 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 lead role in the development and characterization of high-temperature materials 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 1992.

ORNL continues to serve as the lead laboratory for the MMW materials technology program. Although the national materials program was reduced in funding in FY 1988 relative to the FY 1987 budget, critical technology capability was maintained. In FY 1989, a significant increase in activities is planned in support of selected MMW system concepts developed by industrial contractors in FY 1988.

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 ORNL–Oak Ridge-based equivalency of the Grand Junction group 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 5 years because of successful completion of ORNL milestones in these projects. SFMP funding is expected to increase as the amount of decommissioning efforts at federal facilities increases.

CD—Uranium Enrichment

Energy Systems is engaged in a joint effort with 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, about 40 Energy Systems personnel are located on-site at LLNL in key programmatic positions. This on-site effort 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 of the AVLIS development work is being 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 $6.7 million and 16 full-time equivalents for ORNL for 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 establish an extensive 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 the LLNL demonstration facility.

Fuel Recycle Division uranium-processing efforts are 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 product to an oxide suitable for use in the production of reactor-grade UO_2. The Purex-type 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 have been completed; further work at pilot scale is not needed at this time. The program will focus on the modified direct denitration conversion process. Some further development/demonstration of this process appears to be needed, and small quantities of oxide will be produced and provided to fuel fabricators for test purposes. The efforts will be guided by a working interface to be established by the program with fabricators to get industry views and participation in the qualification of this type material for reactor fuel.

Office of Civilian Radioactive Waste Management

ORNL's work for the DOE Office of Civilian Radioactive Waste Management (OCRWM) is conducted under the DB program. ORNL's DB activities currently involve the geologic repository (DB01), transportation and system integration (DB04), and program management and technical support (DB05) (Table 18). Overall, work in the DB programs is expected to remain stable or grow modestly. However, it should be noted that because of the recent enactment of the Nuclear Waste Policy Amendments Act of 1987, ORNL activities financed by the Nuclear Waste Fund are likely to

Table 18. 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	10.95	11.00	10.93	11.03
DC	Civilian Radioactive Waste R&D	0.15	0	0	0
Total		11.10	11.00	10.93	11.03
Percentage of total Laboratory funding—BA		2.3	2.3	1.9	1.7

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

be modified. The nature of such modifications is unknown and must await clarification of budget and programmatic guidelines.

DB—Nuclear Waste Fund

The repository component of the OCRWM program supports the ongoing geotechnical support tasks that have been redirected to directly contribute to and support the Yucca Mountain Project. These tasks include geochemical studies, hydrologic model development, and thermo-mechanical rock property determinations.

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 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 and 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.

Under the second activity, ORNL will provide technical support and will undertake specific technical work related to DOE-CH'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 calculating transportation routes and preparing maps thereof, 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 for 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. Activity in this area is expected to remain stable or grow modestly.

Assistant Secretary for Defense Programs

Programs sponsored by the Assistant Secretary for Defense Programs (ASDP) include Weapons Activities, Verification and Control Technology, Safeguards and Security, Materials Production, and Defense Waste and Transportation Management (Table 19). The most significant new effort in this area involves technical assistance to the New Production Reactor (NPR) program.

GB—Weapons Activities

A variety of tasks and projects are supported by the GB program, including the development

Table 19. 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	1.45	1.72	1.64	0.64
GC	Verification and Control Technology	0	0.25	0.25	0.15
GD	Nuclear Safeguards and Security	0.61	0.49	0.63	0.53
GE	Materials Production	7.5	4.27	5.20	7.15
GF	Defense Waste and Environmental Restoration	27.73	32.11	80.17	116.89
Total		37.29	38.84	86.89	125.36
Percentage of total Laboratory funding—BA		7.8	8.1	15.2	19.7

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

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, technical program assistance for the NPR program, and some support to the Radiation Shielding Information Center (RSIC). Because of the NPR program, the GB program is expected to increase for the next several years, with support remaining constant for the other tasks.

GC—Verification and Control Technology

Laser-induced Resonance Ionization Mass Spectrometry (RIMS) was developed recently to measure isotopes of a variety of elements. This technique offers high immunity to the isobaric interference that is typically encountered in conventional mass spectrometry. The use of sputtering to produce atomic neutral species to be studied by this technique is under investigation also.

Nuclear Fuel Cycle Workshops will continue to be held to acquaint civil service personnel in various federal agencies with the nuclear fuel cycle, especially aspects relevant to nuclear nonproliferation. Participants are provided with information on nuclear fuel reprocessing and are able to establish a link with experts so that they are comfortable with nuclear fuel cycle issues.

GD—Safeguards and Security

This activity, which began 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 project 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; therefore, it has the potential for 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, constructed, and is presently being field-tested.

GE—Materials Production

Two activities are funded by program GE: (1) the ^{252}Cf Industrial Sales/Loans Program and the ^{233}U Storage and Distribution Program and (2) technical support for the NPR program. The activities in support of NPR are expected to increase significantly in the next 5 years.

During FY 1988, the ASDP 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 would conduct a technology and demonstration program. If this program is successful, it will lead to a 4-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 developing technology 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 will review and evaluate all capabilities statements submitted by national laboratories and industry. Assignment of R&D responsibility should be complete by the end of FY 1989.

Energy Systems can provide support for both the HWR and MHTGR in a number of areas of R&D interest. The areas of interest for HWR include the selection of pressure vessel material and irradiation testing of pressure vessel material

(including base metal, weldments, and heat-affected zone at low temperature and low-neutron dose). The areas of interest for the MHTGR include pressure vessel irradiation (work supports both civilian and production reactors), target development (including examination of targets that have been irradiated but not examined), coated particle fuel performance testing, graphite testing (creep, oxidation), and advanced control systems for optimization of power and product production.

The areas of interest for work to support both the HWR and the MHTGR include the following:

- computer code verification and validation (physics, thermal hydraulics, fuel performance, and fission product behavior);
- reliability, availability, maintainability (RAM) analysis for components;
- economic modeling and cost assessment;
- environmental impact statements (EIS) preparation;
- licensing support;
- advanced control systems;
- remote capability for fuel handling (fuel assembly reconstitution); and
- lithium handling (purification, fabrication, enrichment, reprocessing, and quality assurance).

Other activities conducted under the GE program are 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, Tennessee, in April 1988. This 2-day workshop was attended by about 100 people, including DOE, U.S. Department of Defense (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 ^{233}U be renewed. The new facilities would be located in two of the shielded cells at the Radiochemical Engineering Development Center (REDC).

GF—Defense Waste and Transportation Management

ORNL performs research, development, and demonstration activities for the GF program on radioactive, mixed, and hazardous wastes. Examples of R&D projects include (1) paramagnetic separation of waste constituents, (2) bioremediation of mercury contamination, (3) sensitivity and uncertainty analysis of performance analysis codes for LLW disposal, and (4) bioremediation of polychlorinated biphenyl (PCB) contamination. Demonstrations supported under this program include detoxification of the Oak Ridge Y-12 Plant sludges, using roasting technology, and methods for removing volatile organic carbons from groundwater. This area is expected to grow significantly over the next few years as DOE/ASDP expands its efforts to address waste management issues at Defense Program facilities.

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

Two types of LLW are generated at ORNL: solid LLW and liquid LLW. The overall solid LLW management strategy combines waste minimization 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, which should be operational by the early 1990s. The strategy for interim storage of solid LLW is being implemented because of the lack of a central-waste disposal facility and limited remaining disposal capacity in solid-waste storage area (SWSA) 6. High-volume, low-activity solid LLW is being stored at the Oak Ridge Gaseous Diffusion Plant (ORGDP). Solid LLW that is unsuitable for interim storage because of high levels of radiation or shapes unsuited for packaging continues to be disposed of in SWSA 6. Storage and disposal techniques for providing greater confinement are used for all solid LLW. A tumulus-based demonstration is in progress (Fig. 14). Operation of the tumulus will be evaluated by multiyear sampling of liquid taken from the tumulus pad and the underpad collection system. Plans are in progress for constructing additional tumuli in the southeastern portion of SWSA 6 if the initial tumulus demonstration proves successful.

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 limited doubly contained storage capacity. The 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.

- Initiation 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 should be completed by March 1989, will restore some operational flexibility to the liquid LLW system.
- Implementation of in-tank evaporation in the storage tanks for removal of about 150,000 gal of water during the next 5 to 8 years. Initial testing of this approach has been completed satisfactorily.
- Conversion of 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. This will remove most of the current waste inventory from the storage tanks.
- Development of long-term treatment capabilities that will allow production of Low-Level Waste Disposal Development and Demonstration (LLWDDD) Class II waste from future newly generated liquid LLW so that this waste can be disposed of on the Oak Ridge Reservation.

ORNL deals with two types of 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 scans, and X-ray scans. During FY 1988, ORNL 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.

ORNL continues to generate limited quantities of RH TRU waste, and 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 Department of Transportation (DOT) and will be certified with respect to meeting 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 $130-million facility, the Waste Handling and Packaging Plant, is proposed as an FY 1991 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 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 appropriate 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. Some of these activities will be accomplished over relatively short time frames (1 to 5 years), and others may extend for many 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 provides field management for a number of important technologies for the Assistant Secretary for Conservation and Renewable Energy (ASCRE). These assignments cover a wide range of scientific and technical disciplines and are directed by six DOE offices. Ultimate goals are to increase energy efficiency and the use of renewable resources. In so doing, we seek to increase industrial competitiveness, reduce our dependence on oil imports, and reduce the cost of energy to consumers.

Limited government funds are augmented wherever possible by private-sector funds, cooperative research agreements, and cost-shared subcontracts. Relevance to private-sector needs is assured by advisory boards and joint research planning. Particular effort is made to ensure that

research results are made known to industry in a form that will encourage immediate use.

In FY 1988, ORNL, in collaboration with Los Alamos National Laboratory (LANL) and Argonne National Laboratory (ANL), proposed new ways to work with private industry and eliminate barriers to cooperation. Under the program, High-Temperature Superconductivity Pilot Centers, the three laboratories will explore several new approaches to doing research in an exciting new field.

A summary of the major program requirements is given in Table 20.

AK—Electric Energy Systems

The recent scientific breakthroughs in high-temperature superconductors provide a challenge to the scientific community to develop enabling technologies for commercial applications. At the same time there is 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 (based on a proposal by LANL) of High-Temperature Superconductivity Pilot Centers at ORNL, LANL, and ANL. The ORNL pilot center will establish cooperative

Table 20. 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	3.12	4.93	5.45	5.45
AL	Energy Storage Systems	0.87	1.10	1.20	1.25
AM	Geothermal Energy	0.08	0.08	0.08	0.08
AN	Energy Technology Center Program Direction	0.05	0.15	0.15	0.15
CE	Hydropower	0.02	0	0	0
EB	Solar Energy	3.36	2.62	4.10	4.12
EC	Building and Community Services	10.79	11.02	11.33	11.63
ED	Industrial Energy Conservation	2.19	2.52	2.49	2.45
EE	Transportation	17.52	20.26	20.96	21.16
EF	State and Local Programs	0.42	0.30	0.50	0.55
EG	Multisector	6.20	7.41	7.55	8.26
Total		44.62	50.12	53.81	55.10
Percentage of total Laboratory funding—BA		9.4	10.5	9.3	8.7

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

research projects with industrial firms to develop high-temperature superconductivity from a laboratory curiosity 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 will be put in place for the protection of proprietary data, and a simplified model cooperative agreement will be used. The pilot center will also serve a coordinating function for industrial interaction with other superconductivity research at ORNL. Work on the pilot center project began in August 1988.

A second, closely related project is "Development of Practical Conductors Utilizing High-Temperature Oxide Superconductors." This project was established in June 1988 with the goal of obtaining a high-current-carrying, practical conductor using high-T_c oxides. The initial research task is to improve critical current densities in bulk superconducting oxides by developing techniques for the control of grain-boundary properties in powder-produced material. Initial research results have served to reinforce earlier evidence that J_c in 123 material is extremely sensitive to the chemical composition at the grain boundaries.

In other Electric Energy Systems work during FY 1988, the Athens Automation and Control Experiment was successfully concluded, producing a number of significant results for the electric utility industry. Project results were presented at a special session of the IEEE Winter Power Meeting in January 1988.

In future years the funding for applications of high-temperature superconductivity is expected to increase substantially. Support for other research 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 analysis 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 storage concepts are being explored, including use of ammoniated salts for chill storage, development of enhanced heat transfer with ice, and the use of latent thermal storage in building materials.

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

AM—Geothermal

The principal ORNL activity in program AM is research on the chemistry of geothermal systems, and this activity is expected to continue. During FY 1988, measurements of the solubility of gibbsite in buffered NaCl solutions were completed.

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. 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.

Progress was made on several fronts during FY 1988. New productivity records for hybrid poplars were established under subcontract at the University of Washington. Yields from 4-year-old coppiced hardwoods greatly exceeded first-rotation yields, with the best producers averaging 43.5 dry Mg/ha. Wood energy plantation production costs are continuing to decrease and are presently estimated to be between $2.37 and $3.08 per GJ. Three cost-shared monoculture viability trials are now in place.

Recent research results in herbaceous crops include initial selection of sweet sorghum, switchgrass, and reed canary grass as promising species and the completion of the first-year trials of atrazine-resistant rapeseed varieties in the southern corn belt.

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 technology transfer to 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), Building Retrofit 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. In FY 1988, the first experiments were completed in the Large-Scale Climate Simulator, which is the focal point of the Roof Research Center (Fig. 16). This unique facility will be operated as a National User Center, providing the roofing industry with equipment for both generic and proprietary research. The dedication of the facility on September 14, 1988, was attended by 110 persons, including representatives from 57 private companies in the building industry. During the year, ORNL completed a handbook for builders that represents one of the most comprehensive collections of information on good building practice for foundations. BTESM research is expected to continue through the planning period at about the current level. Research is generally cost-shared with industry, and results are disseminated widely, often in the form of input to trade associations for preparation of consensus standards.

In Building Retrofit Research, ORNL is responsible for single-family and commercial buildings. Cooperative projects with several state agencies have greatly improved the state of knowledge concerning the cost effectiveness of retrofit programs. Although the measured energy savings tend to be less than predicted, specific groups of measures have been shown to be highly cost-effective. Increasing emphasis is being given to

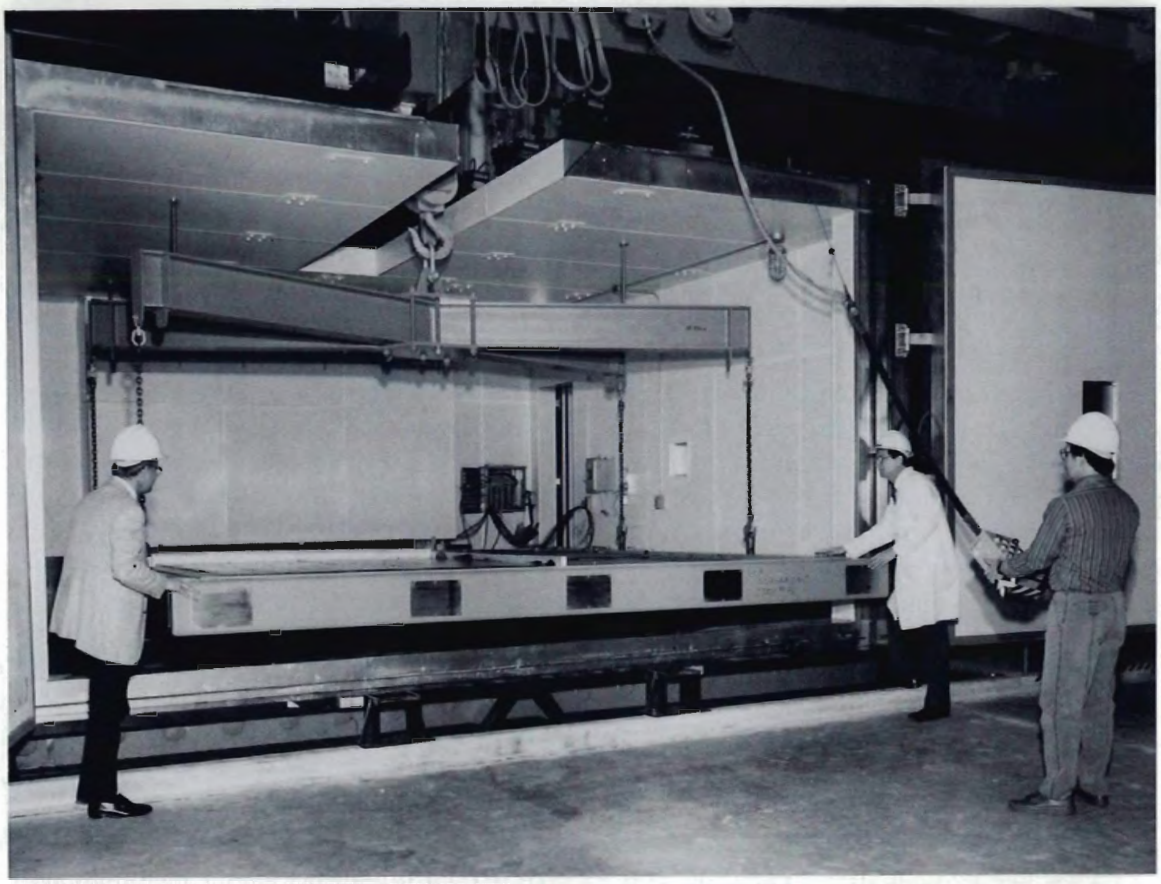


Fig. 16. Test specimen being placed in the Large-Scale Climate Simulator in the Roof Research Center. [From left: George E. Courville, Paul H. Shipp (formerly ORNL, now with USG Corporation), and Phillip W. Childs.]

the efficiency of space-cooling systems in hot, humid climates. Congressional funding levels have been reduced in recent years, making it necessary to be selective in choosing projects.

Building Equipment Research seeks to conserve energy by developing improved heat pumps for heating and cooling of buildings. Both electrically driven and heat-actuated heat pumps are included. A major thrust in electrically driven systems is the search for acceptable substitutes for chlorinated fluorocarbons (CFCs) as working fluids. The recent international agreement (the "Montreal accord") to limit worldwide use of CFCs has increased the urgency of this task. Novel cycles are being examined and cooperative research with chemical companies is being undertaken to determine the properties of alternative fluids. Three types of heat-actuated heat pumps are under development by industrial subcontractors: absorption cycle, Stirling cycle, and internal combustion. ORNL has identified new absorption fluids and cycles with up to twice the performance potentials of the best current systems, and rights have been waived to Martin Marietta Energy Systems, Inc. An exclusive license is being established with a manufacturer for development of

commercial-size units. In future years it is expected that funding for electric heat pumps will decline 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. A new topic in FY 1988 was the establishment of U.S. participation in CADDET, an IEA Center for information exchange on conservation technologies.

An additional project in the EC program is Building Cooperative R&D Ventures. In FY 1988, a survey was completed of the buildings industry needs for research. A cooperative research effort was also initiated with the National Association of Home Builders National Research Center.

ED—Industrial

ORNL is responsible for two 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. During FY 1988 a number of tasks were completed, including the development of a design methodology for fiber-reinforced ceramic heat exchangers and an extensive investigation of ceramic coatings for SiC corrosion protection. In the second project, Chemical Heat Pumps, the objective is to develop heat-pump technology for recovering industrial- and process-waste heat. During FY 1988 encouraging results were obtained in corrosion tests of candidate fluid pairs, and construction was completed on a test loop to measure heat transfer. A new project in FY 1989 will update the available data on prospects for increased recycling of plastic scrap.

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). An additional project, the development of corrosion-resistant materials for use in molten nitrate-nitrite salts, has identified iron and nickel aluminides as particularly promising candidates. Generic research on these materials will also be supported under the EG program.

The level of activity by ORNL on Industrial Programs may increase during the planning period, particularly in materials development, which is a key issue for most industrial conservation projects.

EE—Transportation

ORNL is responsible for three projects in Transportation: Ceramic Technology for Advanced Heat Engines, High Temperature Materials Laboratory (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-saving 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. Recent achievements include an improved process for synthesis and forming of transformation-toughened zirconia (by the Norton Company) and an innovative near-net-shape ceramic-forming process called gel casting (by ORNL researchers) (Fig. 17). Funding for this project is expected to be level during the next several years.

The HTML was completed in FY 1987. This facility houses laboratories and special equipment to support the Office of Transportation Systems,

Fig. 17. A novel process (gel casting) for producing ceramic bodies of near-net-shape has been developed in the ORNL Metals and Ceramics Division. The process is generic in nature and uses in situ polymerization of the binder phase. A. C. Young, the principal investigator, is shown removing fired alumina components from a sintering furnace.

other DOE offices, universities, and industry in advanced materials research. 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. A constant 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 cooperation with the Belvoir Army Fuels and Lubricant Research Laboratory, the project has recently developed a technique that will assist in the formation of a new distillate-ignition-rating system to replace the empirical one that is standard for petroleum products. In FY 1989 this work will be carried to the point of assessing possible commercial application. Another recent study updated the documentation of alcohol fuels utilization technology. Methanol-fueled vehicles have been operated at Lawrence Berkeley Laboratory (LBL), ANL, and ORNL for several years to demonstrate current technology. These tests, which will continue in FY 1989, are giving generally satisfactory experience. However, some problems with component corrosion and difficulties in starting at low temperatures have been identified. It is expected that the Alternative Fuels Utilization Project will continue throughout the planning period.

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 related to the Retrofit Research Project under the EC program. Continuation of this project is contingent on the extent of future congressional appropriations.

EG—Multisector

ORNL has field management responsibility for the Materials Project and participates in the Tribology, Biocatalysis, and Combustion projects—all in the Energy Conversion and Utilization Technologies (ECUT) Program.

ECUT's role is to span the gap between basic science and the engineering development of conservation technologies. Thus, ECUT provides the technology base for efficiency improvements in all end-use sectors.

The ECUT Materials Project is currently exploring eight promising areas of research: superconducting materials, high-temperature materials, lightweight materials, materials by design, thermally insulating materials, biobased materials, corrosion-resistant materials, and materials-processing technology. The ORNL research in the Tribology Project is in the area of friction and wear ceramics; research in the Biocatalysis Project seeks to develop continuous bioreactor technologies for production of chemicals such as ethanol. ORNL's effort in the Combustion Project consists of the development of microemulsions as a substitute for conventional transportation fuels.

In FY 1988 the ECUT Materials Project (in cooperation with the EPRI) undertook a detailed assessment of the various potential end-use applications of high-temperature superconductivity. The use of superconductivity in motors, power electronics, transportation, lighting, electromagnetic pumping, heat pumps, materials fabrication, materials production, and separations was analyzed. For each application the system and materials requirements were determined from both technical and economical standpoints. Further development of several of these applications will be undertaken by ECUT in future years. Exciting FY 1988 results in the use of microwave energy to sinter ceramics have led to a large increase in funding allocated to this task. In another promising development, researchers at Case Western Reserve University, working with ORNL researchers, demonstrated that it is possible to achieve significant room-temperature-tensile ductility in NiAl. ORNL's expectation is that funding for ECUT will remain at the present 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 (ASFE) cover the following areas: coal, gas, petroleum, clean coal technology, and strategic petroleum reserve. The principal focus of the Laboratory's fossil energy activities (Table 21) is related to coal. The coal budget is anticipated to remain at about the same level, with primary emphasis on materials, bioprocessing of coal, and environmental, health, and safety (EH&S) research.

AA—Coal

The principal activities of ORNL's Fossil Energy Program are in the areas of materials for coal conversion and utilization systems; bioprocessing of coal; advanced technologies for coal liquefaction and coal gasification; environmental, health, and safety support related to fossil energy technologies; and fuel-supply modeling.

The materials research activities include management [with the Department of Energy/Oak Ridge Operations (DOE/ORO)] of the Advanced Research and Technology Development (AR&TD) Fossil Energy Materials Program. In this program, ORNL is developing advanced austenitic alloys for use in superheaters and reheaters for fluidized-bed or pulverized-coal combustion. The thrust of this work is to modify existing alloys and to develop new alloys that will meet stringent criteria for strength and corrosion resistance at the high temperatures and pressures of second-generation power plants. In addition to advanced

Table 21. 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	5.88	6.61	7.38	7.02
AZ	Innovative Clean Coal Technology	0.54	0.93	0.95	1.00
SA	Strategic Petroleum Reserve	0.26	0.26	0.28	0.25
Total		6.68	7.80	8.61	8.27
Percentage of total Laboratory funding—BA		1.4	1.6	1.5	1.3

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

austenitic alloys, intermetallic alloys based on iron aluminide (Fe_3Al) are being developed for applications in which superior corrosion resistance and ductility are required. The work on iron aluminides will be expanded to address the issue of improvement in room-temperature ductility. Preliminary experiments indicate that heat-treating techniques are important. The expanded work will involve large heats of material produced by industrial organizations and will be directed to achieving properties that will meet performance criteria for specific applications. The important implications of this work are cost reductions and improved corrosion resistance in the sulfur-bearing atmospheres typical of coal conversion and utilization systems.

Fiber-reinforced ceramic composites with improved strength and toughness are being produced by a novel chemical vapor infiltration and deposition (CVI) process developed at ORNL (Figs. 18 and 19). In this 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 porosity of the composite can be controlled with this process so that both highly dense composites (for purely structural proposes) and porous composites (for filter applications) can be fabricated. These ceramic composites can be used in fossil energy systems such as high-temperature heat exchangers, recuperators, and hot-gas cleanup filters.

Other work on ceramics is devoted to the microwave sintering of sol-gel derived ceramic superconductors and to the evaluation of these materials for application in fossil energy systems. Basic studies of erosion and corrosion are aimed at developing a fundamental understanding of these processes and the relationship of materials properties to resistance to degradation by erosion and corrosion. With a specially modified scanning electron microscope, erosion processes can be

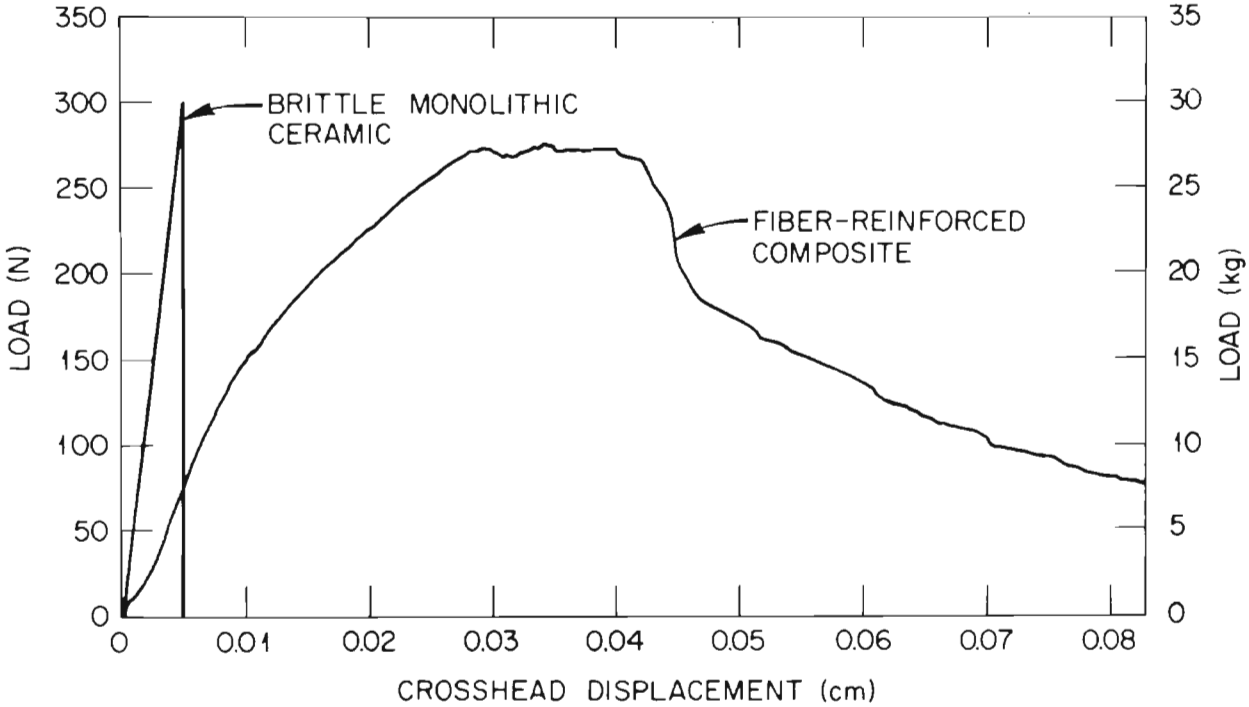


Fig. 18. Precoating of nicalon produced fiber-matrix bonds appropriate for fiber pullout.

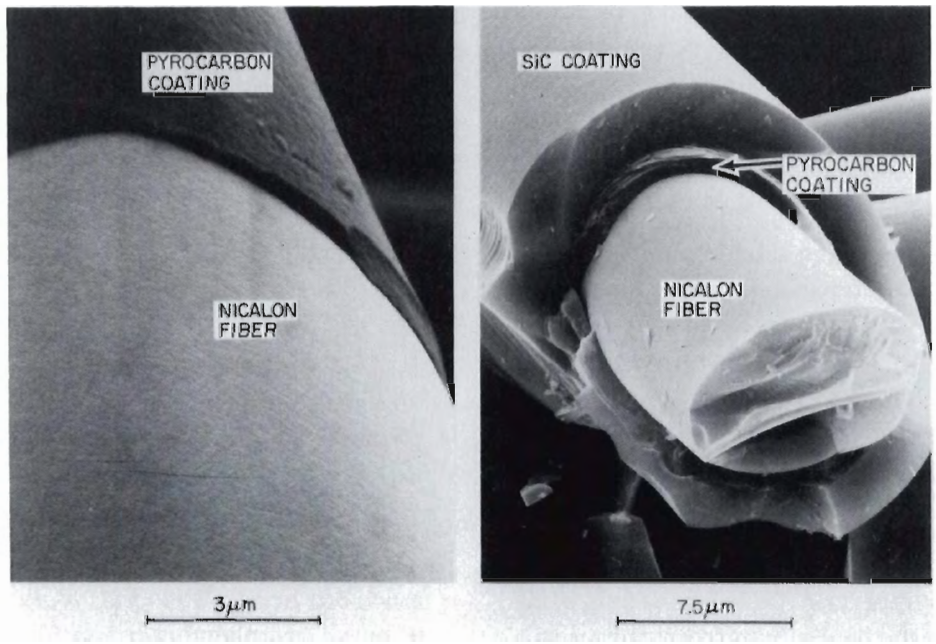


Fig. 19. Carbon interlayer protects fibers and enhances fiber pullout.

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.

The assessments of materials problems and the needed research to solve those problems for a variety of fossil energy technologies are important parts of ORNL's materials effort. Materials technical support was provided to DOE in the operation of the Great Plains Coal Gasification Plant. In addition, ORNL has a commitment to transfer the technology developed on the Fossil Energy Materials Program to others in the fossil energy community. Other materials-related work involves the characterization of coal surfaces and interfaces to better understand coal combustion processes, the development of alloys for hot-gas filter tubesheets, and the evaluation of ceramic membrane materials for the separation of gases in coal conversion and utilization systems. It is expected that the materials effort of the Fossil Energy Program will proceed at about the same level and in the same areas of emphasis over the next 5 years.

Coal conversion work at ORNL involves bioprocessing of coal and the upgrading and evaluation of coal-derived liquids produced by mild gasification processes. Upgrading of the liquids is principally directed to removal of nitrogen-containing compounds by solvent-extraction processes. Physical, chemical, and combustion properties of the liquids are evaluated. The evaluation studies will continue, but the upgrading activity will conclude in FY 1989.

Future work on coal conversion at ORNL will emphasize bioprocessing. This approach 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. It has been demonstrated that enzymes operating in vitro (without microorganisms) can effectively solubilize some types of coal and that both aerobic and anaerobic conditions could be used for the solubilization. This effort has now been extended to a small, bench-scale bioreactor system. Bioprocessing of coal will continue to be an important part of our coal conversion efforts on the Fossil Energy Program during the coming years. A new initiative on bioprocessing in fossil energy is described in the "New Initiatives" section of this document.

The relative use of synthetic and natural fuels is based to a large extent on their availability and market considerations throughout the world. For these reasons, the ORNL Fossil Energy Program is involved in the modeling of fuel supplies and market penetration. ORNL has developed a family of generalized equilibrium models of liquid and gaseous fuel supplies that can be used to analyze the impacts of various policy issues (such as offshore leasing policies) on domestic supplies, as well as to forecast the replacement costs of domestic crude oil. The models can also be used to plan future research directions so that 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.

AB—Gas

There is no current work being performed for the Gas Program.

AC—Petroleum

Work in the Petroleum Program was concluded in FY 1988. This work involved technical and planning support in assessing the role of biotechnology in enhanced oil recovery.

AZ—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 27 projects have been completed by DOE, and a third solicitation will be conducted during FY 1989. This $2.75-billion program will be an important potential funding source for ORNL over the next several years.

ORNL began providing support to CCP with a modest level of funding in late FY 1986. The initial work involved environmental technical support for the preparation of the National Environmental Policy Act (NEPA) reviews of site-specific projects. In addition, ORNL staff assisted in the preparation of a programmatic environmental assessment for the CCP. Materials failure analyses were conducted for the Pittsburgh Energy Technology Center (PETC) during FY 1988.

Support for CCP has grown to about $800 thousand in FY 1989. This effort will include materials work for PETC; environmental work for DOE Headquarters, the PETC, and the Morgantown Energy Technology Center (METC); and information management work for DOE Headquarters. Work in all of these areas is expected to increase as more projects are added to the Clean Coal Program.

SA—Strategic Petroleum Reserve

ORNL is performing work for the Strategic Petroleum Reserve Program in two main areas. One task is to develop 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 enhance and to use several strategic planning models to study the optimal oil stockpile size, crude oil acquisition rates, oil drawdown and distribution capability, and optimal drawdown rates in the event of a disruption in world oil supply (Table 22).

NA—International Affairs

Work for the Office of International Affairs that involved assistance to DOE in the assessment of foreign markets for U.S. coal exports was completed in FY 1988.

Assistant Secretary for Environment, Safety, and Health

ORNL work for the Assistant Secretary for Environment, Safety, and Health (ASESH) 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

Table 22. Strategic Petroleum Reserve major program summary

[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
SA	Strategic petroleum reserve	0.1	0.1	0.1	
	for the second task alone	0.2	0.2	0.2	0.2

Table 23. 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
HA01	Overview and Assessment	8.23	6.05	6.06	6.05
Percentage of total Laboratory funding—BA		1.7	1.3	1.1	1.0

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

with radiological emergencies. Activity at ORNL is funded only under the HA01 program (Table 23).

HA01—Overview and Assessment

ORNL is continuing to provide technical support to the Office of Environmental Guidance and Compliance and to the Office of the NEPA Project Assistance. There is no anticipated change in these compliance activities. ORNL's technical support to the Office of Environmental Guidance and Compliance includes analysis of regulations being promulgated by the EPA under the RCRA; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); and the Safe Drinking Water Act. ORNL staff evaluate regulatory initiatives under these statutes and develop guidance in terms of the technical issues and approaches involved and the potential impacts that the initiatives would have on DOE. Our long-term technical support for compliance with NEPA continues.

For 10 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, the Clean Water Act Review, and the potential effects of global trace-gas emissions. The OEA is expected to fund 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 analysis of proposed EPA changes in diesel fuel and motor gasoline specifications, and a seminar series and publications on "Managing the Global Commons: Decision Making and Conflict Resolution in the Case of Anthropogenic Climate Change." 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 is projected to terminate in FY 1989. ORNL technical support in site prioritization efforts, environmental audits, and emergency response R&D is available.

Office of Operational Safety

A new program is being undertaken in FY 1989 for the Office of Operational Safety, Transportation, and Facility Safety Division. This task will provide 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 will include providing support for the actual performance of compliance appraisals, safety-related program evaluations, and the evaluation of regulatory-related activities.

Assistant Secretary for Management and Administration

ORNL does a small amount of work for the Assistant Secretary for Management and Administration (ASMA) under three budget and reporting codes: WA, WB, and WM (Table 24). WA program work is related to the minority economic impact program. 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.

Table 24. Assistant Secretary for Management and Administration major program summary[a]

[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
WB	In-House Energy Management	0.26	0.08	0.08	0.08
WM	Services	0.09	0.04	0.04	0.04
Total		0.35	0.12	0.12	0.12
Percentage of total Laboratory funding—BA		<0.1	<0.1	<0.1	<0.1

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

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, cogeneration study, and application of energy-efficient motors and chilled water systems.

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 development, testing, production, maintenance, evaluation, and disposal of weapons. Production cost uncertainties must also be studied to provide a method to determine confidence intervals of future weapons-cost estimates.

Office of Policy, Planning, and Analysis

Work for the Office of Policy, Planning, and Analysis is now at a modest level, with similar future levels anticipated (Table 25). This work involves analyses of policies related to the transportation sector, automotive efficiency, and alternative fuels.

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.

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 (Table 26).

Table 25. Office of Policy, Planning, and Analysis major program summary[a]

[$ in millions—budget authorization (BA)]

Budget and reporting code	Major program	Fiscal year			
		1988	1989	1990	1991
PE	Policy Analysis and System Studies	0.22	0.35	0.34	0.34

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

Table 26. 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	1.07	1.50	1.77	1.77

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

Work for Other DOE Programs and Installations

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 Resources. This research has focused primarily on the performance of residential energy retrofit programs. More 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. Energy Division will also extend its leadership in the fields of AI and power systems by developing an expert system prototype to process Bonneville's microwave communication system alarms. Resource requirements and projections for work performed at the Laboratory for other DOE contractors and operations offices are shown in Table 27.

Table 27. Work for other DOE programs and installations program summary[a]

[$ in millions—budget authorization (BA)]

Program area	Fiscal year			
	1988	1989	1990	1991
Fission	6.36	4.80	4.80	4.80
Biological and Environmental	4.35	4.40	4.50	4.50
Basic Physical Sciences	0.27	0.75	0.72	0.76
Fusion	2.47	3.10	4.40	4.20
Fossil	0.15	0	0	0
Conservation and Renewable Energy	0.23	0.80	0.80	0.80
Other	4.32	1.88	1.13	1.13
Total	18.15	15.73	16.35	16.19
Percentage of total Laboratory funding—BA	3.8	3.3	2.8	2.5

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

Work for Others

Federal Organizations

Nuclear Regulatory Commission

Current ORNL efforts for the Nuclear Regulatory Commission (NRC) reflect the changing commission priorities, public attitudes toward the safety of nuclear power, and the maturing of the U.S. nuclear industry. The slowdown in construction of nuclear plants, coupled 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 accident sequence analysis. Continued reduction of the NRC research budget has resulted in an increased cooperative effort with other countries in severe core damage accident research. Research support will undoubtedly increase in areas related to materials evaluation and plant aging, whereas studies of the behavior of fission products in severe accidents are expected to decline as various issues are resolved. Because of the establishment by the NRC of a federally funded R&D center, technical support to high-level waste repository licensing activities will be virtually eliminated at ORNL in FY 1989 and beyond.

Based on the above scenarios, increased funding is expected for FY 1989 and FY 1990 from the Office of Nuclear Regulatory Research and is anticipated to remain stable thereafter. Funding from the Office of Nuclear Reactor Regulation and the Office for Analysis and Evaluation of Operational Data is anticipated to remain constant throughout this planning period, whereas funding from the Office of Nuclear Material Safety and Safeguards will decline during the upcoming fiscal year and then stabilize. Overall, based on current NRC budget projections, ORNL efforts are expected to remain stable for FY 1989, increase for FY 1990, and then stabilize (Table 28).

Table 28. Nuclear Regulatory Commission program resource summary by fiscal year

[operating $ in millions—budget and authorization (BA)]

Major program office	1988	1989	1990	1991
Nuclear Reactor Regulation	0.36	0.35	0.35	0.35
Nuclear Material Safety and Safeguards	1.03	0.34	0.31	0.31
Nuclear Regulatory Research	10.71	11.23	12.70	12.70
Analysis and Evaluation of Operational Data	2.21	2.25	2.60	2.60
Other offices	0.13	0.21	0.11	0.11
Total	14.44	14.38	16.07	16.07

Department of Defense

The DOD supports a wide range of research at ORNL where the Laboratory's unique capabilities and technologies directly contribute to the nation's defense. Work is performed for three primary services of DOD (Army, Navy/Marines, and Air Force), as well as joint agencies such as the Defense Advanced Research Project Agency (DARPA), Defense Nuclear Agency (DNA), Strategic Defense Initiative Organization (SDIO), Organization of Joint Chiefs of Staff (OJCS), Office of the Assistant Secretary of Defense (OASD), National Aerospace Plane Program, Transportation Operating Agencies, U.S. Transportation Command, and others. Major ORNL programmatic support to DOD includes Data Systems Research and Development (DSRD), the Strategic Defense Initiative (SDI), Hazardous Waste Management, Acoustics and Instrumentation R&D, and Defense Technology Programs (DTPs). These R&D programs are discussed in this section, and the budgets are listed in Table 29.

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 ORNL's work for DOD through the formation of a coordinated program area for Space and Defense Technology (SDT).

Table 29. Department of Defense major program summary

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

Major program office	Fiscal year			
	1988	1989	1990	1991
Army	5.73	10.68	12.13	12.20
Navy	1.98	6.70	7.50	8.50
Air Force	6.10	9.84	11.23	11.24
Other DOD	0.93	3.70	6.70	7.70
Total DOD	14.74	30.92	37.56	39.64
Data Systems Research and Development[b]	35.61	15.70	15.70	15.70
Hazardous Waste R&D[b]	8.79	6.50	7.50	8.00
Grand total	59.14	53.12	60.76	63.34
Percentage of total Laboratory funding—BA	12.4	11.1	10.50	9.96

[a]Includes subcontracts and funding required to support personnel required from other sites.

[b]ORNL support of "Central" managed programs.

The SDT program consolidates the work conducted under the SDI, 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 three major DOD services (Army, Navy/Marines, and Air Force), as well as for joint agencies such as SDIO, DARPA, DNA, and several other defense-related agencies. The SDT program involves work at all three Oak Ridge plants.

Army ORNL research for the Army includes programs in materials science and technology, environmental analysis, transportation systems, operations research, and environmental analysis and assessment. This work 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 munitions stockpiles. ORNL continues to support major environmental assessments for the safe disposal of obsolete chemical weapons stockpiles and the Installation Restoration Program. These assessments include the development of emergency evacuation plans.

Work areas that are expected to expand include environmental analysis to assess the potential impact of changing military operations at specific sites or broader programmatic missions, including developing new environmental measurement techniques; analytical chemistry efforts 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 fuels research; and advanced materials R&D in composites, ceramics, carbon/carbon, intermetallics, and related technologies for the development of advanced armor or lighter-weight components for increased mobility.

Research to develop new systems to modernize emergency planning, transportation, recruiting, force structure, and related systems for the National Guard Bureau is expected 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. Funding for this work is expected to decrease next year because some major production efforts will be completed; however, funding is expected to increase again in FY 1990 and succeeding years.

ORNL continues to play an important role in instrumentation and engineering R&D for the David W. Taylor Naval Ship R&D Center (DTRC). DTRC is the 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) structural 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 complete submarines and components. 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 advanced submarine 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).

Other projects for the Navy include some conducted by the Applied Technology Division (ATD), which has conducted R&D projects totaling $6 million since September 1986, for the Naval Underwater Systems Center (NUSC). These projects supported the Torpedo Silencing Research Vehicle (TSRV), Mark 48 Torpedo, and acoustic-, launch-, and flow-systems technologies. They are expected to continue at approximately $2 to 3 million per year. Areas of R&D for which ATD provides support include conceptual and detailed component designs, structural analyses, composite-damping and thermal-imaging investigations, digital-data-acquisition system and test-data-algorithm development, image recognition, robotics, and composite/metal component hardware fabrication.

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

ORNL also provides technical support to the Navy Environmental Health Center on health hazard evaluations of new substances to be used in Navy operations. Assistance is also provided in the preparation of materials safety data sheets required by the Occupational Safety and Health Administration (OSHA) to be available at Navy installations.

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

ATD is currently working with the Air Force Wright Aeronautical Laboratory (AFWAL) on the development and evaluation of thermoplastic composite materials for space applications, fabrication techniques for thick composites, a laser-based thermoplastic consolidation system, and foil-lined composites for cryogenic environment applications.

A major 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.

A major program expansion is expected to support the development of the Airlift Deployment Analysis System for the Military Airlift Command and related traffic routing and scheduling research for the Air Force Logistics Command.

Advanced materials work for the Air Force includes the evaluation of lightweight structures. This evaluation uses the extensive expertise developed in the weapons and centrifuge programs for the fabrication and testing of high-temperature carbon/carbon composites and other high-strength materials.

ORNL is also providing assistance in health-protection and hazardous-materials management through work on the *Air Force Toxicology Guide* and through the evaluation of adverse health effects and risk assessments related to hazardous chemicals found at Air Force installations.

Strategic Defense Initiative The SDI program uses the special capabilities of all three Oak Ridge plants. Work is currently being done 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 next administration.

Several significant program changes are possible in the next few years. The SDI Survivable Optics Manufacturing Operations Development

and Integration Laboratory (MODIL) program and the Radioisotopic Thermoelectric Generator/Dynamic Isotope Power System (RTG/DIPS) 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 to FY 1990. The Neutral Particle Beam program is expected to be phased out by early FY 1989.

The MODIL program is a major new SDI initiative that was begun in FY 1988 and is planned to continue at an expanded pace in FY 1989. This program will examine and integrate optical technologies into an overall fabrication process. It will examine the broad scope of the manufacturing system as opposed to the singular development of manufacturing subsystems. It will provide the integrated technology that, if implemented by private industry, would achieve the stated SDI optical performance 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 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. Since mid-FY 1986, direction, management, and contracting support for DSRD has been performed outside ORNL.

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,
- data-base structures,
- advanced computing systems support,
- communications systems,
- logistics systems development, and
- statistical and numerical methods.

Some of the DSRD projects to which ORNL contributes include a simulator sickness project, a project to study advanced techniques for composite-materials analysis for the Naval Air Systems Command, and a contingency-analysis (modeling) project for the OJCF. 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. Work for the Navy Regional Data Automation Center consists of projects for estimating the cost of Automated Data Processing (ADP) services and an expert system for design and planning of telecommunications networks. Other expert-systems research encompasses various management information system projects for the Army Modernization Program, Headquarters Tyndall Air Force Base, and Naval Sea Systems Command.

Hazardous Waste Research and Development The varied and complex waste issues 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 DOE 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 technological support to the various EPA regions and the EPA Hazardous Waste Engineering Research Laboratory, 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. We also have an active effort in site characterization for various federal sponsors.

Technology development is currently provided to the Air Force Engineering and Services Center, NEESA, and the EPA. Projects include removal of volatile organics from soil and groundwater; separation of heavy metals from sand; paint stripping, using plastic media blasting; 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.

Department of Health and Human Services

The Department of Health and Human Services (DHHS) supports research in carcinogenesis, genetics, and toxicology. Its funding is expected to remain reasonably constant through FY 1989 (Table 30). 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:

- the National Cancer Institute;
- the National Institute of Environmental Health Sciences;
- the National Heart, Lung, and Blood Institute;

Table 30. Department of Health and Human Services program resource summary

[$ in millions—budget authorization (BA)]

Major program	Fiscal year			
	1988	1989	1990	1991
Department of Health and Human Services	5.3	5.3	5.5	5.5

- the National Institute of General Medical Sciences;
- the National Institute of Child Health and Human Development;
- the National Institute on Drug Abuse;
- the National Library of Medicine;
- the National Toxicology Program; and
- the Agency for Toxic Substances and Disease Registry (ATSDR).

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.

The FDA 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.

NIH, through NCI, supports environmental research on the fate of radioiodine in food chains. Collaborative hazardous waste research with The University of Tennessee is anticipated through the National Institute of Environmental Health Sciences (NIEHS) Superfund Program.

Environmental Protection Agency

Overall, our EPA program will continue at about the FY-1988 level of effort throughout the planning cycle, with fluctuations in specific program areas (Table 31). Our work for EPA addresses numerous health and environmental problems and issues, particularly research in the toxic effects of pollutants associated with energy-production processes and waste disposal. Health risk analysis and epidemiological studies continue to be important components of this work. We will become involved in the development of biomarkers for assessing exposure and effects of environmental contaminants.

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.

EPA is also supporting research at ORNL to evaluate the impact of municipal waste

Table 31. Environmental Protection Agency program resource summary

[$ in millions—budget authorization (BA)]

Major program	Fiscal year		
	1988	1989	1990
Environmental Protection Agency	4.7	5.0	5.0

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.

Data-base development activities for EPA increased in FY 1988 and are expected to increase in FY 1989 and beyond. An evaluated data base, chemical unit risk estimate (CURE), is under development for the Office of Environmental Criteria and Assessment. CURE will be an on-line interactive file to be used by EPA scientists and regional offices for performing chemical risk assessment.

Acidic deposition research activities are generally stable. 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. The Laboratory's role in data analysis for the national survey of streams will decrease in FY 1989, but support for the Direct/Delayed Response Program will remain stable. ORNL is supporting program planning and development for a new EPA initiative in Long-Term Environmental Monitoring and Assessment (LEMA) in FY 1989.

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 centers on using ecosystem models to assess the risks of chemical releases to aquatic environments as well as 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. New work has been initiated 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. In FY 1988, new work began in analyzing environmental issues and options for the Office of the Administration.

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 linked-global-element cycles and for the development and application of new methodologies for analyzing ecosystem- and landscape-level problems. The nutrient-cycling and ecosystem resilience project continues to develop food-web simulation models to evaluate the resiliency of ecosystems to disturbances. ORNL will continue to explore its potential contributions to the planned Department of Interior (DOI)/NSF/DOE interagency Continental Drilling Program. Another research effort sponsored by NSF involves development of a fiber-optic-based fluoroimmuno-sensor (FIS), an instrument using monoclonal antibodies and laser-induced luminescence for the detection of trace levels of biological species in body fluids (Table 32).

With NSF support, ORNL staff are developing biologically based pharmacokinetic and

Table 32. National Science Foundation program resource summary

[$ in millions—budget authorization (BA)]

Major program	Fiscal year		
	1988	1989	1990
National Science Foundation	1.2	1.5	1.5

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 ratemeters 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
- expedient production of antibiotics.

These programs are expected to continue at a stable level (Table 33).

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

Table 33. Federal Emergency Management Agency program resource summary

[$ in millions—budget authorization (BA)]

Major program	Fiscal year			
	1988	1989	1990	1991
Federal Emergency Management Agency	1.67	2.00	2.33	2.33

(FHWA) on research into vehicle-miles-of-travel (VMT) forecasting for both automobile and truck traffic (Table 34).

To support these analytical efforts, and in cooperation with agencies within DOE and DOD, ORNL has been the leader in development of an

Table 34. Department of Transportation program resource summary

[$ in millions—budget authorization (BA)]

Major program	Fiscal year			
	1988	1989	1990	1991
Department of Transportation	0.40	0.51	0.52	0.52

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 useful to both DOE and FHWA policy and planning staffs. ORNL is also increasingly involved in helping FHWA select and make best use of sampling methods for the collection and analysis of truck freight transportation information.

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.

Agency for International Development

ORNL serves as the 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 and analysis and information dissemination. In addition, ORNL provides technical assistance in project development, implementation planning, and evaluation related to

energy planning, power system development, renewable energy technologies, and fossil energy technologies. Future funding is expected to remain stable.

Department of the Treasury

ORNL performs research for the Bureau of Engraving and Printing, a branch of the U.S. Department of the Treasury. Tasks under way include development of high-speed prototype machines for Web Currency Inspection, Web Stamp Inspection, and Web Currency Finishing. The first two prototypes use machine inspection to locate and mark printing flaws. The third prototype extracts flawed bank notes and adds sequential serial numbers and Federal Reserve Bank seals to the unflawed notes. Analytical models based on flaw-severity surveys are used in calibrating the inspection systems to human-perception standards. Security document printing provides a significant challenge for automated inspection. Research in counterfeit deterrence and ink chemistry also is under way. Security document production, counterfeit deterrence, and automation through machine inspection are nationally important issues.

DOI, 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 and the development and use of federal land.

Other Federal Agencies

ORNL also provides technical support to a variety of other federal agencies. The Consumer Project Safety Commission, DOI, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Department of Agriculture (USDA) support small amounts of life sciences research. We anticipate collaborative work with the USDA's Forest Service in environmental research. Some support for FY 1988 came from the U.S. Department of State for work performed for International Atomic Energy Agency (IAEA) and UNESCO. Collaborative research for the Park Service is beginning at the Great Smoky Mountains National Park. Also included are the U.S. Department of Education, U.S. Department of Justice, U.S. Department of Labor, and TVA (Table 35).

ORNL is developing innovative resource modeling techniques that will be applied to analyses of minerals economics and to the development and use of federal land. The first studies in this program are estimating the economic impacts of acid rain legislation on the minerals industry and developing specifications for software to simulate geologic resource endowment in unexplored areas.

Table 35. Other Federal Agency program resource summary

[$ in millions—budget authorization (BA)]

Major program	Fiscal year			
	1988	1989	1990	1991
Other Federal Agency	9.15	14.62	18.91	16.63

Nonfederal Organizations

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.

Electric Power Research Institute

Research sponsored by EPRI addresses critical national issues related to electric power generation. Major efforts in this area are 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 serves a lead role for EPRI in the Integrated Forest Study on the Effects of Atmospheric Deposition, the evaluation of the response of pine seedlings and associated soils to ozone and acid rain in the Controlled Air Pollution Facility, and the Fish Compensation Project.

EPRI continues to fund research at ORNL in areas related to the efficient use of electric energy (Table 36). Efficiency research projects sponsored by EPRI that are currently under way include testing of full-size ice-storage systems for cooling commercial buildings, a laboratory investigation of the use of direct expansion ground coils in ground-coupled heat pumps, 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.

Gas Research Institute

DOE and the Gas Research Institute (GRI) have a number of common interests related to the efficient use of natural gas. GRI has funded work at ORNL that looks at energy-use characteristics of commercial buildings. GRI has also been involved in DOE-sponsored field tests of gas

Table 36. Electric Power Research Institute program resource summary

[$ in millions—budget authorization (BA)]

Major program	Fiscal year			
	1988	1989	1990	1991
Electric Power Research Institute	4.6	5.0	5.0	5.0

equipment retrofits in residences. For a number of years, DOE and GRI have been cooperating in the area research on thermally activated heat pumps.

This cooperation has ranged from each participating on the other's project review committees to carrying out coordinated research projects on specific research topics. For example, GRI is cofunding the development at the Trane Company of a triple-effect absorption chiller, which promises to be about 50% more efficient than the best current absorption chillers. The triple-effect cycle was conceived at ORNL under the DOE Building Equipment Research Program, and the development project at Trane is being carried out under a license to that patent. DOE is continuing to fund work at ORNL that is related to advanced absorption cycles, including basic research on absorption fluids and heat and mass transfer in absorption and adsorption processes that may be critical to the successful development of the triple-effect and other advanced absorption cycles.

Other Nonfederal Organizations

ORNL performs work for several nonfederal organizations:

- the United Kingdom Atomic Energy Agency;
- the Japan Atomic Energy Research Institute;
- the Taiwan Power Company;
- the Canadian Atomic Energy Commission;
- the International Atomic Energy Agency;
- the National Institute of Radiation Protection of Sweden;
- Harvard University;
- the universities of Georgia, Illinois, Maryland, and Wyoming;
- the states of California and Virginia;
- Metropolitan Edison/General Public Utility;
- Pacific Power and Light;
- EG&G Energy Measurements, Inc.;
- the Florida Institute of Phosphate Research;
- Gulf Oil;
- Battelle Laboratories;
- General Electric;
- the American Petroleum Institute; and
- the National Association of Homebuilders Research Foundation.

The total funding from all these nonfederal sources is shown in Table 37.

Other ORNL Programs

Robotics and Intelligent Systems Program

ORNL has formed the Robotics and Intelligence Systems Program (RISP) because the development and demonstration of remote technology efforts of the CFRP and the longer-range research studies of the CESAR program are complementary. RISP includes studies of robotics, teleoperations, and related aspects of intelligent machines such as AI and parallel computing. As

Table 37. Other nonfederal program resource summary

[$ in millions—budget authorization (BA)]

Major program	Fiscal year			
	1988	1989	1990	1991
Other nonfederal organizations	1.79	2.13	1.83	1.81

such, it is inherently interdisciplinary and includes scientists and engineers from several ORNL divisions. RISP includes all ORNL robotics and related intelligent-system activities for DOE, DOD, NASA, and other sponsors. The program seeks to contribute technology toward important problems in nuclear, environmental, space, and waste-management technologies.

Applied Technology Division

The Applied Technology Division (ATD) became part of ORNL in 1988. It was created in FY 1985 using the facilities and personnel that had been involved in R&D on the gas centrifuge technology for uranium enrichment. In the subsequent 3 years, the division changed its emphasis on centrifuge technology and evolved into providing R&D support for other DOE and other government programs, emerging technologies, and national competitive initiatives. 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:

- national leadership in the application of advanced composite materials;
- 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 analysis;
- extensive experience in complex systems design, operation, and evaluation; and
- a full range of analytical and design capabilities in high-speed machinery to understand and handle various factors such as stress, supersonic hydrodynamics, structural considerations, thermal dynamics, acoustical vibration, and both conventional and unconventional bearing technology.

The advanced technology capabilities of ATD in advanced 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 potential national and international technology leadership. Currently, ATD has over 40 organizations from DOE, DOD, and the private sector sponsoring this work.

Examples of current advanced technology applications are:

- a prototype pressure hull for the Navy submersible surveillance submarine that is considered to be a significant development in the application of advanced materials to Navy submersible structures;
- the development of a compact data-acquisition system for use by the Navy to develop advanced torpedo technology;
- the development of a phosphor-based temperature-measurement system for the Air Force for application in the development of advanced turbine engines; and
- the development of an innovative, compact, high-power-density superconducting motor for EPRI and DOE, which has significant potential for defense and commercial applications.

Major program initiatives within ATD include the following:

- an organic matrix composites initiative as a focus for nationwide R&D in composite systems, including reliability and life performance;
- 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; and

- 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.

Waste Management Technology Center

The Waste Management Technology Center (WMTC) established during FY 1986 by Energy Systems and DOE-ORO is evolving as planned. The WMTC now has technical management responsibility for two major programs encompassing all ORO sites and is currently pursuing several related initiatives within the ORO complex (Table 38).

The first major program managed by the WMTC is the LLWDDD Program. This program has responsibility for defining and demonstrating improved waste management technologies for low-level solid wastes generated within the ORO complex, for siting new disposal facilities to be used by the three plants on the Oak Ridge Reservation, for coordinating the preparation of an Environmental Impact Statement for new disposal facilities on the reservation, and for designing and constructing large-scale disposal demonstration units within the new facilities. Several LLWDDD demonstration projects were initiated during FY 1986 and FY 1987. These projects include above-grade, earth-mounded disposal systems based on information exchanges with France that provided the use of their experience with similar technology, the evaluation of various waste-packaging materials and technologies, and the evaluation of mechanical volume-reduction technologies based on super-compaction processes. All these projects have involved private participants through competitive procurement processes with emphasis on the selection of innovative mobile technologies or waste treatment. Scheduled demonstrations of waste immobilization and advanced waste-packaging technologies have been advertised. Preliminary bids from vendors were received by the end of FY 1987. Several contracts were awarded in FY 1988. Demonstrations of diverse treatment, storage, and disposal technologies will continue into the 1990s.

The second major program managed by the WMTC is the Hazardous Waste Disposal Development and Demonstration (HAZWDDD) Program. This program was established in FY 1987 and is modeled after the LLWDDD Program. The objective of the HAZWDDD Program is to identify and coordinate the needed technology development for the management of hazardous mixed wastes at the five Energy Systems sites and to identify and demonstrate the needed waste management technologies developed by the private sector.

In addition, the WMTC has the responsibility for several initiatives that are expected to expand in FY 1989 and beyond. For example, the

Table 38. Budget and personnel projections by fiscal year for WMTC

	1988	1989	1990	1991	1992	1993	1994
Dollars (in millions)	8	10	15	15	15	15	15
FTEs							
Technical	12	15	20	20	20	20	20
Other direct	8	10	12	12	12	12	12

Hazardous Waste Technology Program (HWTP) manages 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 the series of workshops on the following subjects: leaching tests, uranium-bearing wastes, contaminated soils, and RCRA/CERCLA issues. The workshops were well received by the sites and are expected to continue and to cover other waste mangement topics of interest to the sites. In the future, this activity could even include the publication of a WMTC newsletter summarizing WMTC technology demonstrations and other related activities.

In addition to conducting the LLWDDD and HAZWDDD waste management demonstrations, WMTC works with the National Hazardous Waste Remedial Action Program (HAZWRAP) to identify and manage technology demonstrations for other sponsors such as DOD agencies and EPA. WMTC also works 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 facilities (Table 39).

WMTC, depending upon resource availability, has conducted and will conduct special studies related to waste management. For example, WTMC staff participated in the recently conducted Strategic Alternatives Study (SAS) by HAZWRAP to develop a set of waste management options applicable to DOE-Defense Program hazardous and mixed wastes.

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. One of the project's most important goals is to bring Smart House cabling, electrical control devices, consumer appliances, and gas projects into the market for homes constructed in the 1990s. (Estimate funding at ~$200 thousand for FY 1989.)

Table 39. HBCU budget and personnel projections by fiscal year for WMTC

	1990	1991	1992	1993	1994
Dollars (in millions)	0.5	0.5	0.5	0.5	0.5
FTEs					
Technical	1.5	1.5	1.5	1.5	1.5
Other direct	1.0	1.0	1.0	1.0	1.0

Site and Facilities

Site and Facilities

Laboratory Description

The Oak Ridge National Laboratory (ORNL) is the largest and oldest of the five multiprogram energy research laboratories. Its programmatic base dictates the long-term use of most existing permanent facilities and continues to cause a significant deficit of adequate office housing and the requirements to replace obsolete temporary housing.

The Laboratory has about 4.1 million square feet of gross building area. About 2.7 million square feet is located at the main Bethel Valley site and the Melton Valley site to the south, and the remaining 1.4 million square feet is located at the Oak Ridge Y-12 Plant. A few buildings are located in the remote areas south of Melton Valley. Over 50 ORNL personnel are also located in several facilities at the Oak Ridge Gaseous Diffusion Plant (ORGDP).

ORNL has full facilities responsibility for the main site and remote areas. However, for the facilities at the Y-12 Plant, the Laboratory has full responsibility for the maintenance of buildings and limited responsibility for the site's infrastructure. At ORGDP, the Laboratory has limited responsibility for both buildings and infrastructure because both are shared with other tenants.

About one-half of ORNL's total existing building area was constructed in the 1940s; over 80% was completed before 1965. The age and resultant condition of the buildings are significant factors in shaping the long-term building plans.

Some of the least desirable space has been deemed marginal and has been placed in the Strategic Facilities Initiative (SFI) for removal. Some replacement space has been constructed with general plant project (GPP) funds in recent years. Line-item projects are expected to address building replacement or revitalization in FY 1990. However, much more must be accomplished to keep the Laboratory's buildings viable for the long term.

The Laboratory's infrastructure has received important revitalization funding support in recent years. As a result, major improvements have been or are being made to the sanitary sewer, water, central chilled water, electrical, and steam distribution systems as well as to roads and parking areas. Major work remains to correct deficiencies in the electrical, steam generation/distribution, and water systems; roads and parking areas; and the nonradiological wastewater and low-level wastewater (LLW) systems.

In addition to the ongoing maintenance of facilities, numerous line items, GPPs, and expense projects are being pursued to ensure that appropriate facility conditions are provided.

Facilities, Plans, and Options

The resources used to maintain or improve the Laboratory's facilities include the following:

- line-item construction (both program and general purpose),
- general plant projects (both general and special purpose),
- capital equipment (both program and general purpose),

- real and nonreal property maintenance, and
- other expense-funded tasks including Strategic Facilities Utilization Projects.

All of these resources are required and must be adequately supported for the Laboratory to continue as a vital research institution for the U.S. Department of Energy (DOE) and the nation. Details of the Laboratory's major construction projects through the planning period are reflected in Table A.6 (Appendix). However, this section will focus on maintenance, GPP, and general-purpose equipment (GPE) levels. The Laboratory GPP and GPE summaries are shown in Table 40.

Current Situation

Recent levels of GPP (AT program) funding and anticipated levels through the baseline planning period are shown in Table 41. ORNL's budget requests and projections through 1994 are shown for comparison. ORNL also receives GPP funds from GF, KG02, and WB programs. These programs provide special-purpose funds that have limited application to the maintenance and enhancement of the Laboratory's overall capabilities.

The anticipated low level of FY 1989 AT-GPP funding and the lack of significant recovery in the remainder of the planning period are causes for concern. Progress was made in the mid-1980s to increase GPP budgets. This was a positive sign that the Laboratory's facilities needs would be addressed. However, this positive trend must continue in order to ensure that the Laboratory's facilities are fit for their intended research and development (R&D) and support missions.

Recent levels of GPE (AT program) funding and anticipated levels are shown in Table 42. ORNL's budget requests and projections through

Table 40. GPP and GPE funding needs through FY 1994

($ in millions)

	1988	1989	1990	1991	1992	1993	1994
GPP							
General laboratory GPP (AT program)	7.20	8.60	9.45	9.80	10.20	10.60	11.10
Environmental compliance (KG02 program)	0	4.00	4.00	4.00	4.00	4.00	4.00
Defense waste (GF program)	2.46	3.45	3.50	3.50	3.50	3.50	3.50
Energy conservation (WB program)	0.15	0	0	0	0	0	0
Total GPP funding	9.81	16.05	16.95	17.30	17.70	18.10	18.60
GPE							
AT program	3.80	10.60	10.30	10.70	11.10	11.50	12.00
KG program	0.40	0.40	0.40	0.40	0.40	0.40	0.40

Table 41. Recent and projected levels of program AT GPP and ORNL's budget request

($ in millions)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Actual and anticipated	7.0	7.2	6.6	7.2	6.6	7.0	6.6	7.2	6.6	7.0
Requests and projections	6.0	8.0	8.7	8.2	8.6	9.4	9.8	10.2	10.6	11.1

Table 42. Recent and projected levels of program AT GPE and ORNL's budget request

($ in millions)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Actual and anticipated	3.80	3.80	3.82	3.77	3.80	3.80	3.80	3.80	3.80	3.80
Requests and projections	6.3	7.1	17.0	6.0	10.6	10.3	10.70	11.10	11.50	12.00

1994 are shown for comparison. This disparity of GPE funding request vs authorizations is evident in Table 42. ORNL budget requests reflect current requirements to preserve or enhance equipment and do not significantly impact our backlog of aged, obsolete equipment, which was bought during the 1950s and 1960s. Estimates of GPE requirements based on need indicate that a higher level is required than is shown in the Laboratory's budget requests.

The current levels and lack of anticipated upward movement of GPE funding remain an acute concern. The anticipated funding shown reflects a decline in funding when inflation is considered. State-of-the-art research requires state-of-the-art equipment. This requires adequate programmatic equipment and GPE funding to provide the needed resources. Support equipment must be reasonably current to maintain required reliability and cost-effective operation. Simply maintaining the status quo in GPE funding will result in continued degradation of ORNL's equipment assets.

Looking Ahead

ORNL has, over the past decade, made numerous in-depth assessments of its capital assets from various qualitative and quantitative perspectives. These assessments have taken many forms, and a few of them include the following:

- 1979—Assessment of Facilities (Yellow Book),
- 1980–1982—Multiprogram General-Purpose Facilities (MGPF) Assessment of Facilities,
- 1982–1984—ORNL Facilities Evaluation Studies,
- 1984–1988—Assessments of existing conditions of the facilities in the Site Development Plans,

- 1985—Multiprogram Energy Laboratories–General-Purpose Facilities (MEL-GPF) Revitalization Program, and
- 1986–1988—SFI, Site Strategic Facilities Plan.

These assessments have been conducted to appraise the status and condition of the site's facilities. From these assessments, several static "scenarios of need" have been generated that have resulted in funding for selected areas of revitalization and site improvement (Fig. 20). However, it is becoming increasingly apparent and important in these times of leaner national R&D budgets that the maintenance of high-quality, high-efficiency, and longer-lived research and support facilities will require longer-term, longer-range, and more strategically planned management and utilization of available capital funds.

In recognition of this situation, ORNL has formed a working group to characterize and analyze the entire process and mechanism for planning and projecting the total Laboratory capital asset needs. This working group comprises members representing the relevant planning and operational organizations, and the objective is to develop a recommendation for the thorough characterization, planning, project identification and capital projects management for the Laboratory. Ideally, the recommendations included in this proposal will base the capital assets management and planning on traceable and quantifiable elements of the future of the major research and development missions and objectives of the Laboratory.

Concurrent with this Laboratory capital assets planning initiative, DOE will need to play the

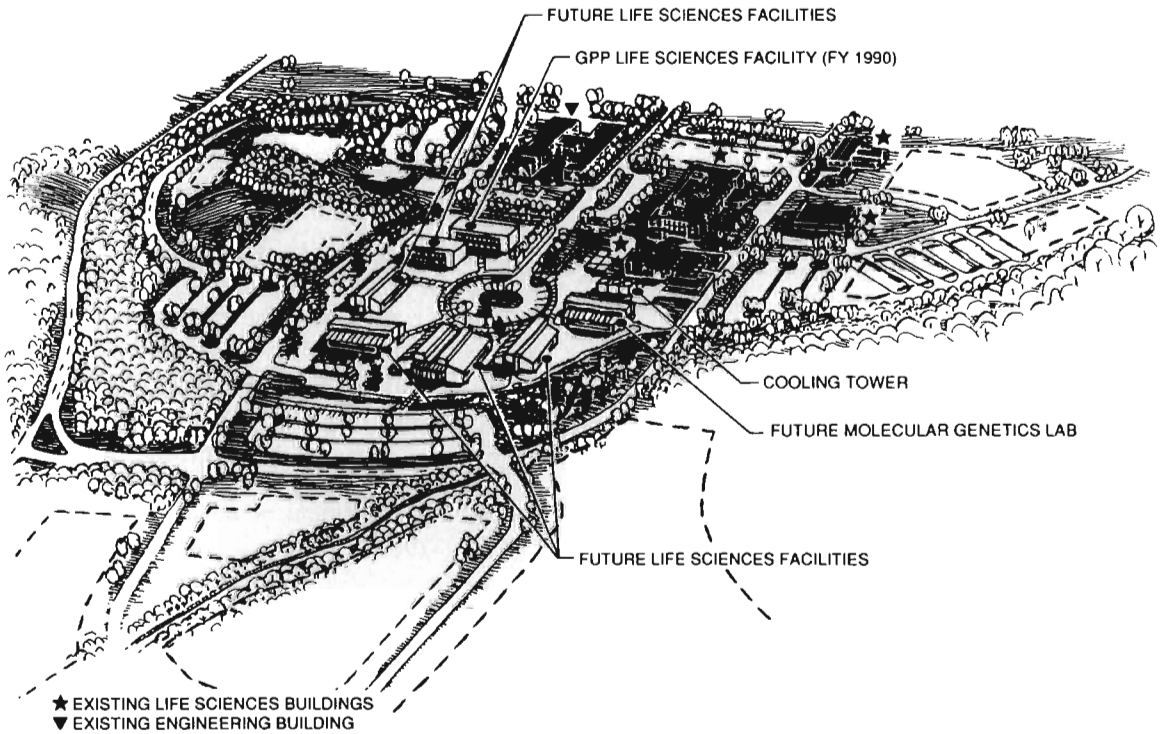


Fig. 20. Proposed Life Sciences Complex.

major role in funding the identified capital needs in both programmatic and plant maintenance areas. This combination of thorough needs assessment/identification and the DOE funding of these requirements will ensure the long-term vitality of ORNL.

In summary, the Laboratory is addressing the future of the capital assets planning process and intends to demonstrate an increasingly comprehensive and firmly based foundation and definition of capital assets needs. Correspondingly, continued and increased support for the upgrade and maintenance of ORNL's programmatic and support operations through all available DOE program offices is essential.

Data-Processing and Telecommunications Requirements

During this past year, ORNL management issued the following mission statement: "It is the long-range objective of ORNL to provide the ORNL research staff with computing resources that are known to be the very best among non-weapons laboratories of DOE." This mission arose out of an increased awareness of the research productivity gains possible with improved computational resources coupled with reliable high-speed communications networks and the researchers' need to attack new classes of problems to remain competitive. In addition, an improved administrative support system was needed to address new requirements for project tracking, management, and reporting. A committee was formed to address these issues and establish the planning framework, develop implementation strategies, and define a method for measuring the progress toward ORNL's computing goals. As a result of the committee's efforts, a draft version of the *ORNL Strategic Plan for Computing* has been prepared and is being reviewed by Laboratory management. The plan is based upon a concept of the problem requirements and the supporting structure necessary for this solution by the end of the planning period (Fig. 21).

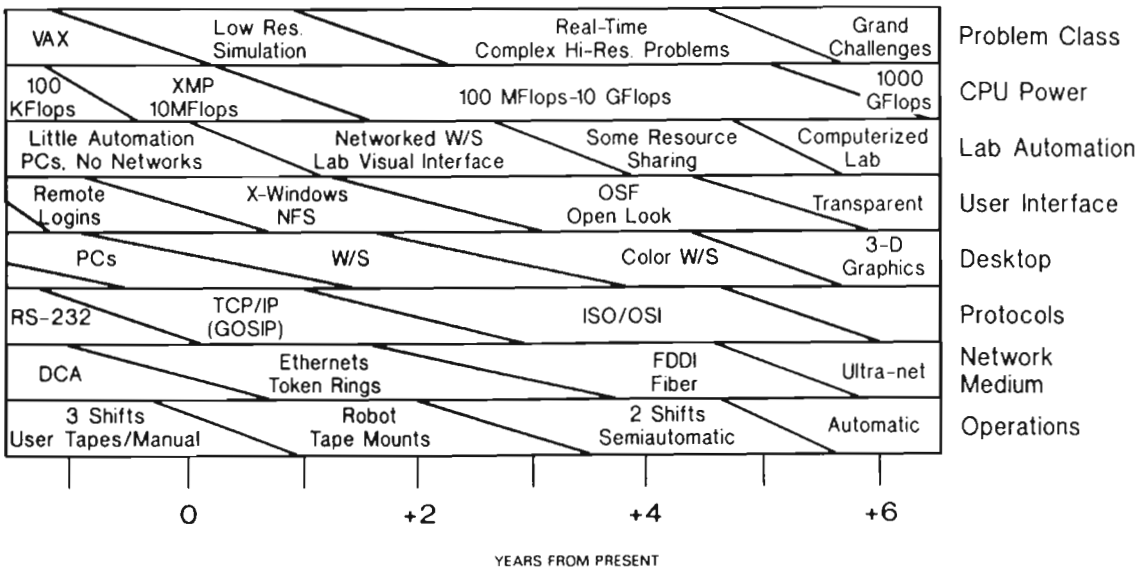


Fig. 21. ORNL computing concept.

To solve the problems anticipated, to improve the Laboratory's competitive position, and to enhance the researchers' effectiveness, the Laboratory must provide the capability to solve real-time, complex, high-resolution problems for many users and "grand challenges" for a few users. The experimenter requires simple methods to acquire, analyze, and integrate data with results obtained in remote laboratories. The support required to provide these capabilities is shown in Fig. 21.

The important features of Fig. 21 are the problem class, laboratory automation, the user interface and protocols, the desktop devices, and the network medium. Each of these is briefly discussed in the following sections.

Problem Class

The problem class defines the categories of problems being solved. Currently, many problems are tailored for the existing VAX class machines. Usually, problems are tailored to run no more than 24 to 48 h on these machines. With the acquisition of the Cray, a new problem class is established: that of a 4- to 8-h Cray run, which is the equivalent of a 240- to 480-h VAX 780 run. Complex high-resolution problems will require orders of magnitude more computational power. This power will be achieved in the future by massive parallel computers. Current plans call for the acquisition of a massive parallel machine in the 1- to 10-Gflop range during the planning period. Grand-challenge problems will require even larger and faster computers. The solutions of these problems will have major effects on the nation and its economy, or will solve major fundamental scientific problems.

Laboratory Automation

Currently, most laboratory data-acquisition and analysis problems are custom solutions. The advent of high-speed networks, file sharing, remote procedure calls, and visual interfaces make it possible to provide more standardized laboratory interfaces and to prepare methods that allow data sharing between different research groups who need not be aware of the method or form of data storage. Systems are needed that allow the experimenter to experiment, not write programs. Packages are appearing and standards are available, but integration, management, and recommendations in this area are needed.

User Interface and Protocols

Currently, user interfaces to computers differ from computer to computer and from application to application. Users must log into specific machines to get specific functions. The advent of networked workstations, standards, remote procedure calls (RPCs), and network file systems provide mechanisms to remove the requirement of determining which machine to log into. To improve productivity, the workstation itself will be required to determine the location of the necessary service and obtain that service without the user's knowledge; it will appear as if that service was available on the user's workstation.

The appearance of standardized protocols such as TCP/IP, GOSIP, OSI, and X-Windows will provide a mechanism to accomplish this. However, to provide a consistent presentation level to the user, a standard "look and feel" and a standard method of accessing services need to be defined. This is necessary to reduce training time, improve efficiency, and eliminate conversions each time equipment is changed. For example, standardization will determine whether HELP is obtained by using a pull-down or pop-up menu and whether a *DO Manual* is available as a program to be run or as a menu item labeled "MANUALS."

Very efficient programs can be developed, but maximum efficiency can be achieved by the use of consistent, intuitive user interfaces that reduce training and support time.

Desktop Devices

Although "dumb" terminals are still being used, the current desktop device is the PC connected to host machines via low-speed connections. Figure 22 shows the anticipated introduction of other desktop devices and the plans for replacing existing ones. The specifications of three-dimensional color, two-dimensional color, and monochrome are indications of the performance characteristics and uses for these devices. Three-dimensional color assumes the requirement for real-time building, rotation, and shading of complex three-dimensional color objects with lighting effects. These machines require significantly more computational and graphics capabilities than do two-dimensional color or monochrome machines.

Network Medium

The requirements for communications bandwidth increase as researchers use higher-performance workstations, share data, access distributed data bases, and begin to employ interactive visualization to explore complex problems (Fig. 23). While twisted pair, operating at 9600 baud, is the predominant communication medium at this time, some installation of coaxial cable has taken place within the Laboratory, allowing upwards of 10 million bits per second (Mbits/s) to be transferred. Visualization and the effective use of high-performance workstations require bit transfer rates from 100 Mbits/s up into the gigabit-per-second range. This will probably require fiber-optic trunks initially and fiber-optic connections to the scientist's workstation

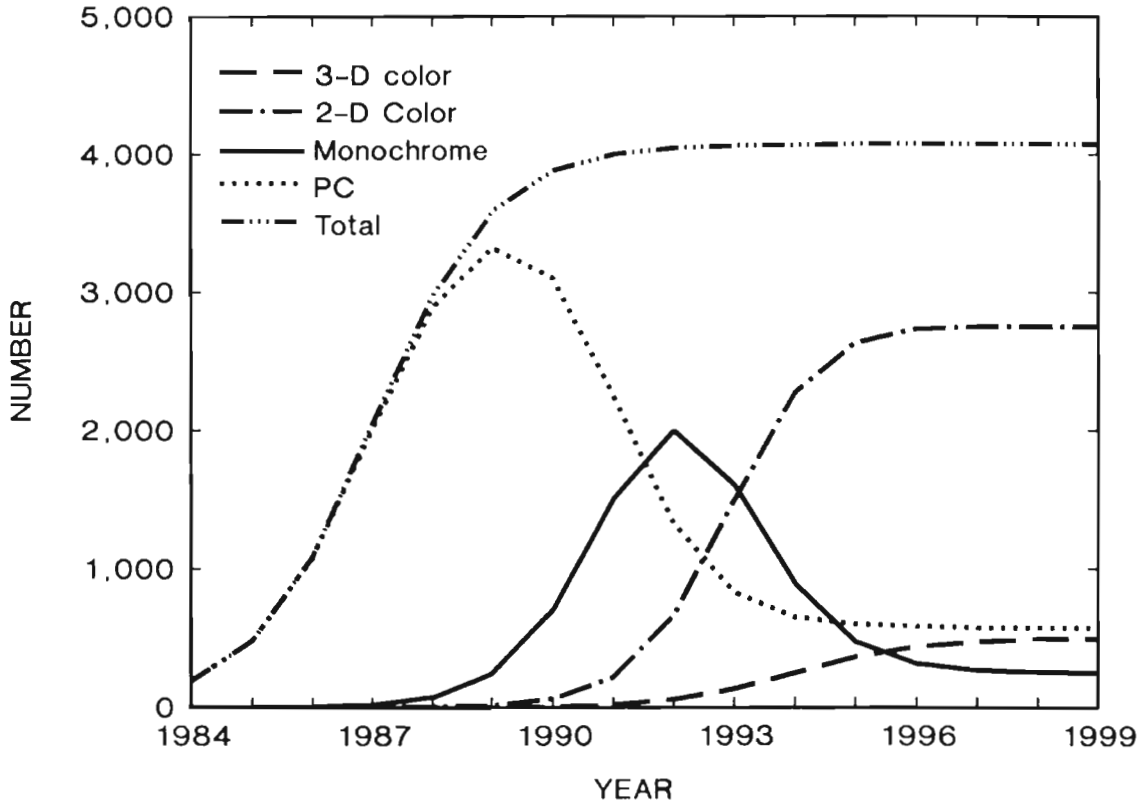


Fig. 22. Evolution of desktop units.

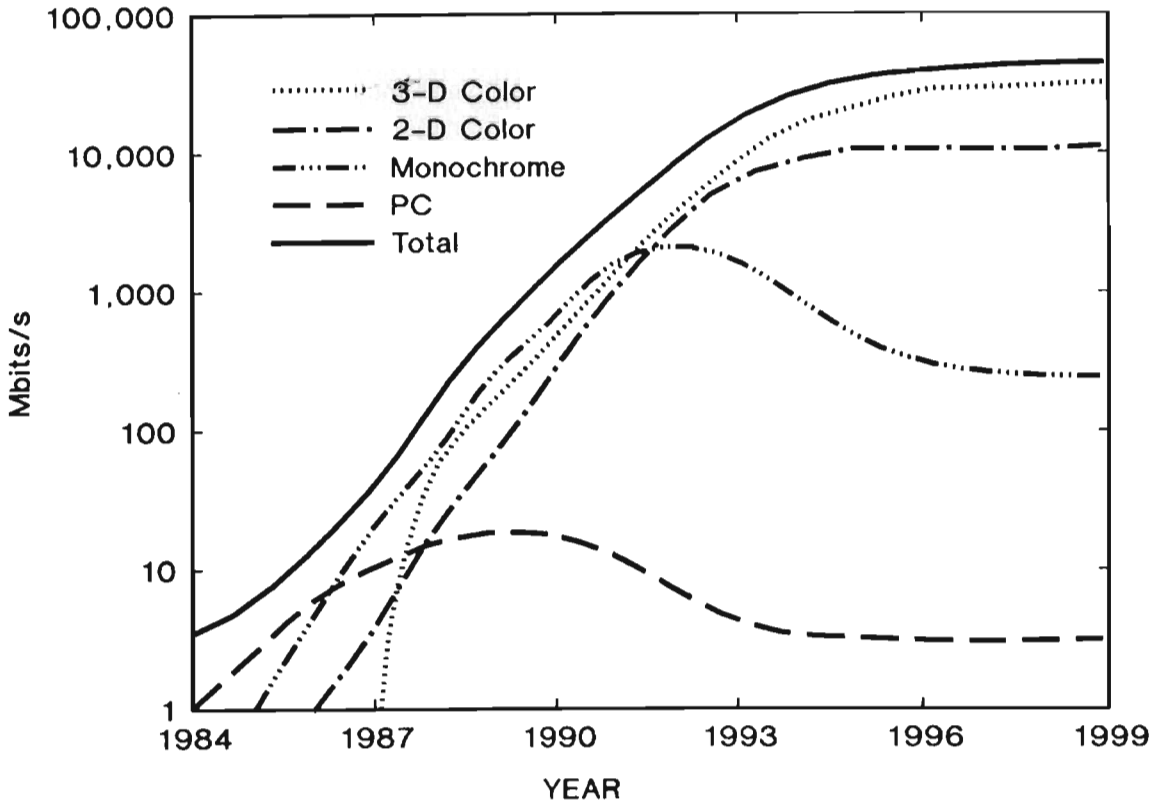


Fig. 23. Required bandwidth.

eventually. Methods exist to obtain Gbits/s transmission rates and should be investigated for selected applications during the early part of the planning period.

The current telecommunications plans provide for fiber-optic trunks to be in place by FY 1992 as part of a telephone system upgrade. To effectively use and provide an atmosphere for innovative research and uses of computers in research, funds should be provided for initiating the installation of optical fiber within the ORNL site on a faster time scale. In addition, the extension of optical fiber to some researchers' desktops will be required during this same period.

Large costs are associated with providing very high speed (100 to 10,000 Mbits/s) between sites and over large distances within sites. For that reason, it will be appropriate to investigate the trade-offs between widespread installation of extremely high-bandwidth networks and establishing high-performance centers for visualization and bandwidth-intensive applications. The objective should be to maximize the use of our computational resources in innovative and imaginative research.

Lower Costs in Some Areas To Improve Others

To support changes in computing capability in the face of essentially flat budgets, it will be necessary to become more efficient in some areas and reduce service in others. The saved funds must be invested in improving capabilities in

strategically selected areas, with the objective of attracting additional funding through evidence of cost effectiveness, good management, and ability to be innovative.

Any manpower-intensive area should be examined for potential savings. These areas should be carefully considered as long-range planning is necessary to minimize the effects of changes on the staff and the associated environment. Examples can be found in the Laboratory environment in the areas of tape mounting and computer operations.

Trend Toward Automation

As part of a move toward automation, the Computing and Telecommunications Division (C&TD) is implementing control centers from which a few operators can monitor and control several remote computers. To improve the efficiency of these centers, movement toward automating this activity needs to be accelerated, with the goal of "lights-out" operations. With the advent of robot storage devices (thus requiring no tape mounts), a fairly simple workstation can be configured to monitor several computers. This monitor would filter out of the message streams those actions that would require human intervention and would signal an appropriate operator at that time. Furthermore, these same workstations could be extended to monitor network connections and remote computer status and to notify the appropriate operator when necessary.

So-called "lights-out" operations would have staff-level effects. Therefore, it is especially important that planning for these possibilities begins soon and addresses methods to relocate and retrain personnel.

Low-Cost Storage

Another area where costs can be redirected is in storage. The large data bases used by environmental and global models, geographical data, pollutant data, and others place great demands on storage space. If disks alone are used, the cost can be prohibitive. If tapes alone are used, the costs increase significantly.

Recently, robotic devices have been developed commercially that allow massive amounts of data to be stored very cost effectively without human intervention. These devices also provide methods to manage data so that users always access their data from disk and never mount a tape directly or even become aware of the tape's existence. The growth of data within the Laboratory indicates a need for a solution of this type as part of the package of reducing operational costs and providing improved service to the Laboratory.

The above requirements are grouped for solution into the four areas described below.

Computer-Augmented Research Environment The Computer-Augmented Research Environment will provide basic support for ORNL research activities whereby researchers will have convenient, responsive access to a logically interconnected system of computers, data bases, and code libraries. This capability will provide robust support for the visualization of complex phenomena, simulation, modeling, data acquisition and analysis, and scientific calculations. It will also provide convenient access to national scientific networks and data bases through a consistent responsive interface and support for the preparation and high-speed exchange of quality documents without compromises in graphical-representation or scientific-notation capabilities.

Strategies for achieving this objective include selecting standardized scientific workstations that provide simple methods for obtaining appropriately configured systems with intuitive interfaces to other networked resources; moving aggressively toward conformance with de facto industry standards such as POSIX, GOSIP, SQL-X-Windows, and Sun Microsystems' open standard Network File System (NFS); moving aggressively toward providing ORNL professional staff with

robust high-bandwidth data networks; providing cost-effective, transparent, large-volume data-storage options; installing fiber-optic wiring to most researchers' offices; and optimizing the physical location of major resources in order to minimize the cost of very high-bandwidth interplant data communications.

National Recognition ORNL will continue to be recognized nationally for its research work in computer-related areas such as parallel processing, expert systems, and the "electronic scientific library." Strategic acquisitions will be made to support these areas.

Innovative Management ORNL will be recognized as the provider of effective direction for the management of computer resources, with particular emphasis on the alignment of computer expenditures with Laboratory strategic objectives and the achievement of high efficiencies in computer-support operations.

Administrative Support ORNL managers and staff will have convenient access to administrative information necessary for the effective management of ORNL programs. This information will be timely, accurate, secure, well-documented, and easily combined for ad hoc needs.

Actions During FY 1989

During FY 1989, several actions are scheduled to demonstrate the movement toward meeting several of the Laboratory's objectives and goals.

Workstation Procurement A technical specification has been developed that will meet the majority of Energy Systems' workstation requirements. The selection of several vendors should be completed during FY 1989. A wide variety of workstations, peripherals, and software offering a range of performances and prices will have been competitively bid and available in a simplified manner to the research and administrative staff. All equipment obtained through this method will be interoperable and capable of sharing resources with existing and future equipment that conforms to a minimal set of standards.

UNIX Node on STC During the early part of FY 1989, a VAX 785 computer will be added to the STC cluster, providing a UNIX environment for scientific and technical users. This will assist users in preparing for the planned Cray conversion to UNICOS and will provide a larger shareable resource for the workstations anticipated.

NFS and TCP/IP To Be Made Widely Available Current plans provide for expanding the use of TCP/IP and NFS. TCP/IP, a protocol that allows computer communication independent of manufacturer, and NFS, which allows "transparent" users sharing or access to computer files irrespective of their physical location, will be extended to IBM, VAX, and other manufacturers' equipment. This will allow user data storage to be obtained and installed where it is most cost effective, while still appearing to be physically attached to the computer being used.

Cray Conversion to UNICOS The Cray XMP located at ORGDP currently uses the CTSS operating system developed at the National Magnetic Fusion Energy Computing Center to provide time-sharing and batch services for the Cray computers located in Livermore, California, and at several other Office of Energy Research (OER) centers. As part of the movement toward standard operating systems, the Cray at ORGDP will be converted during FY 1989 to use the UNICOS operating system provided by Cray Research. This operating system is Cray's implementation of the UNIX operating system on the Cray XMP architecture and is expected to become compliant with POSIX and GOSIP in the

near future. This will allow computer codes developed for any other POSIX-compliant operating system to be moved to the Cray and vice versa with very little modification. Development of codes may be carried out on workstations and then moved to the Cray for final execution. Also, the capability will exist for providing Cray computational services through the use of transparent RPCs, thus extending supercomputer services to non-Cray users for some problems.

Central Computer Expenditures by ORNL

Data-storage costs were about equal to computational costs during the FY 1986–FY 1988 period (Fig. 24). Computational expenditures are expected to decrease as more users employ workstations for a large portion of their work. In addition, unless lower-cost central file servers become available, more local disks will be obtained, leading to a reduction in expenditures for central data storage. As workstations become more prevalent, the amount spent for office automation, electronic mail, and other current central services will decrease. A significant change in these expenditure levels during FY 1989 is not expected; however, the trend will be downward and will accelerate as technology advances.

Changes in technology, reinforced by revenue limitations, will affect several areas, two of which are storage costs and local workstations.

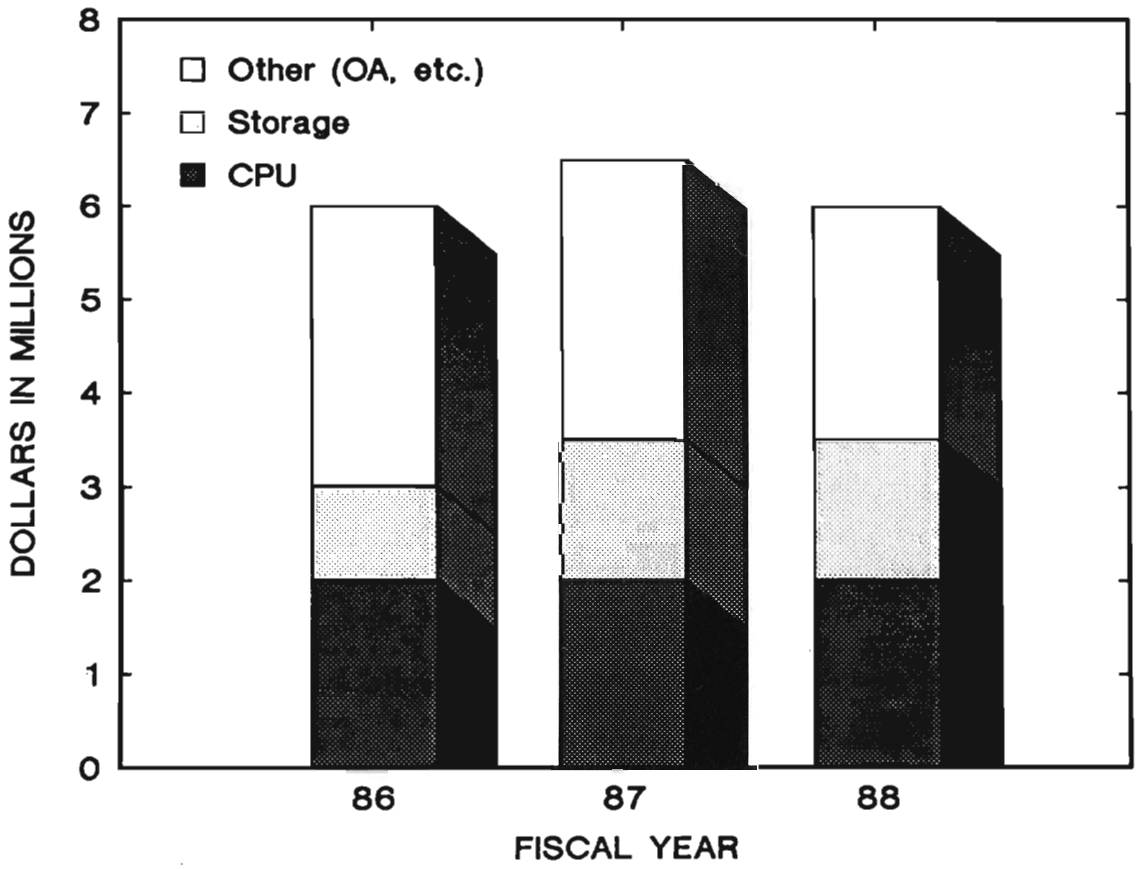


Fig. 24. Three-year ORNL expenditures for central computing.

Storage Costs: Movement To Locate Storage Currently, ORNL has access to an IBM 3850 mass store device, which is obsolete and will soon be removed. The only available alternatives that offer low-cost storage are the Central File System (CFS) associated with the Cray at ORGDP and round tapes located at ORNL. The CFS system is not available whenever the Cray runs in classified mode, and with the Cray located at ORGDP and connected by the relatively low-speed interplant broadband, operation as an ORNL storage device would be impractical. In addition, the CFS system does not provide transparent access to user files but rather requires user action to retrieve and save files within specified time periods, sometimes resulting in the loss of important user data. The use of round tapes can be a low-cost option, but it results in job delays and requires operators to be present to mount tapes. Furthermore, it would result in increased charges for tape-based jobs if expanded. The lack of low-cost data-storage options for the future will tend to drive users toward acquiring desktop data-storage devices. These devices can be obtained using expense funds. They are reliable and provide adequate performance for many desktop computers, but their performance is not comparable with storage devices associated with the centrally managed computers.

Costs and Performance It is now possible to acquire a 20-megabyte storage device for a local workstation for about $800 (about $40 per megabyte). This can be compared with mainframe data storage devices, which cost about $8 to $10 per megabyte. In addition, mainframe storage devices provide significantly higher seek rates, transfer rates, and lower access times than local storage, even when accessed over a 10-Mbit/s network.

Risks There is a corporate risk inherent with acquiring local hard-disk storage with operating funds rather than obtaining adequate capital funds to acquire mainframe hard-disk storage. Individuals may not provide adequate measures to ensure data integrity and recovery from hardware or software failures; therefore, the success of important missions may be jeopardized. In addition, each instance of local disk storage means the duplication of requirements for system software storage. When the costs associated with storage duplication are added to the costs of highly paid staff providing adequate, individual backups for each instance of local storage, it is clear that more balanced approaches and methods need to be developed.

Possible Solutions Reductions in the cost of data storage and provisions for a more balanced data-storage environment would reduce the risk of loss or corruption of important data. Current technology can provide centrally managed, low-cost mass storage as network nodes that appear to be local data storage from the user's perspective. When coupled with a hierarchy of group, departmental, and divisional file-servers that are centrally maintained and operated, centrally managed storage could provide a reasonable alternative to the growth of large individual data-storage devices. While such solutions are being considered it is important that they be developed and implemented soon to provide low-cost, well-managed data storage options when individuals are considering the acquisition of new local data-storage devices.

Workstations and the Movement to Local Computing Just as technology is driving the costs of local storage down to the point where individuals can acquire them, so too is the cost of computing being driven down. Five years ago, a division was considered fortunate if it could acquire a VAX 780 computer, costing over $250,000, for its entire computing needs. Current industry developments provide individual researchers with that much computing power for less than $5000. These new systems include improved bit-mapped graphics displays and improved user software.

Because the researcher's job has changed, such computer power is required to be competitive. The importance of interaction, rapid predictable response times, and visualization have been demonstrated at several research centers. As the power of the local workstation increases, more individuals will require this interface to enhance productivity and remain competitive.

Costs and Performance Historically, the cost of computing has constantly dropped, but nowhere has it dropped more rapidly than in the PC and workstation area. The availability of a VAX 780 computer's power for one individual for $5000 is impressive, but not when measured against the forecasts of industry savants who predict that the computational performance of the Cray will be available for the desktop for $5000 to $10,000 within the planning period.

If these costs are so low for such performance, why use larger central machines at all? The key is in the use of the words "computational performance." The desktop device can execute instructions as fast as a Cray, but more than that is required of a supercomputer. Supercomputers are usually used for solving super problems that require massive amounts of memory and/or very high-speed data-storage devices. The costs of the associated peripherals and memory to use a supercomputer effectively can equal or exceed the cost of the computer. The cost of high-speed data storage devices to support supercomputing or the massive amounts of memory required if high-speed data storage is eliminated probably will not drop low enough to provide true supercomputing on the desktop. The power provided by the new desktop devices will be used instead to provide new capabilities such as improved graphical interfaces, signal processing (such as voice recognition and synthesis), and improved user interactions.

Risks Some problems can be tailored to run on desktop configurations by reducing the scope of the problem or by running for extended periods. Because the workstations will be obtained individually, there is the risk that users will begin to avoid using central facilities, including true supercomputers, and tailor problems to the workstation to avoid central costs. In the short term, this could reduce expenditures, but will be costly in terms of productivity in the long term. For example, a job that runs for 24 h on a workstation might very well be completed in 24 min on a central Cray computer.

Possible Solutions An environment is required that does not place artificial barriers on the method used to solve scientific problems (such as how funds are earmarked as expense or capital). Those portions of the problem that can be solved appropriately using central shared resources should be solved using those resources, while those portions best done on the desktop (such as editing and displaying data) should be done there. Three things must be developed to enhance productivity and use resources effectively: networks, code libraries using remote access to appropriate resources, and human intuitive interfaces.

Cost Recovery in a Distributed Environment

As a network is developed and a truly distributed environment becomes possible, the issues of cost recovery arise. What methods will the Laboratory use to fund the computing environment of the future? If a cost-recovery method is used, then it must address how to allow users to access automatically chosen, differing remote resources without incurring unpredictable costs.

In addition, if workstations are locally acquired and "owned," how are the costs for services such as backup, programming assistance, and some server-based functions such as mail to be paid? Currently, most central-support functions are supported from central machine revenues, which are expected to decline as the use of workstations and PCs increases. The requirements of the users will continue, however, even though the users cease to use the central machines.

Summary

A concept has been developed depicting what computing should be like for ORNL in the future. This strategy defines objectives in several areas and goals to measure progress toward those objectives. Actions have taken place and more are planned for FY 1989 in accordance with the strategy. The funding picture does not look promising, but in this area, technology can be used to improve computing at about the same expenditure level if properly coordinated. Many decisions need to be made to provide the planned environment in the time frame necessary to remain competitive; priorities need to be established and shifts in emphasis made. ORNL management has established an important mission in the area of computing support that can benefit ORNL staff at all levels. It is now necessary to carefully coordinate the various actions that are required to fulfill the mission in a timely and effective manner. With the support of the service divisions, funding programs, operations offices, and ORNL management, the future looks good for computing at ORNL.

External Interactions

Technology Transfer

To a growing extent, the exceptional scientific and technical developments that emanate from the Oak Ridge National Laboratory (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.

Collaborative research efforts with industry, on either a one-on-one basis or through research and development (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

Since 1985, patent waivers on several ORNL innovations have been granted, and Energy Systems has used them to aggressively pursue commercial licensing. The following steps are taken to license technologies that are ready for commercialization:

- identify technologies with commercial potential,
- conduct market opportunity analyses,

- fund technology maturation projects if needed,
- develop and implement licensing strategies,
- request a waiver from DOE, and
- negotiate licenses with industry.

At the end of FY 1988, we had 24 license agreements in place with 22 firms in 10 different technology areas (Fig. 25).

The vigorous pursuit of technology licensing agreements such as these will help rejuvenate U.S. industry and its competitiveness in the world market. Our policy requires that products from these licenses, if sold on the U.S. market, must be substantially produced in the United States. This ensures that all firms pursuing domestic markets will have similar capital and labor costs. U.S. taxpayers gain in two ways: jobs are generated for American workers, and higher tax revenues are received from the increased economic activity. In an effort to encourage domestic manufacturing for sales in foreign countries, we also provide incentives in our licenses for export sales.

Our success is derived from the fact that we are now able to offer these ORNL technologies to U.S. companies under conditions that make investment in their commercial development attractive and potentially profitable. For example, an ORNL-developed ceramic composite that is toughened with ceramic "whiskers" has been licensed to seven industrial firms, principally for applications in industrial cutting tools and wear parts (Fig. 26). This technology is already being

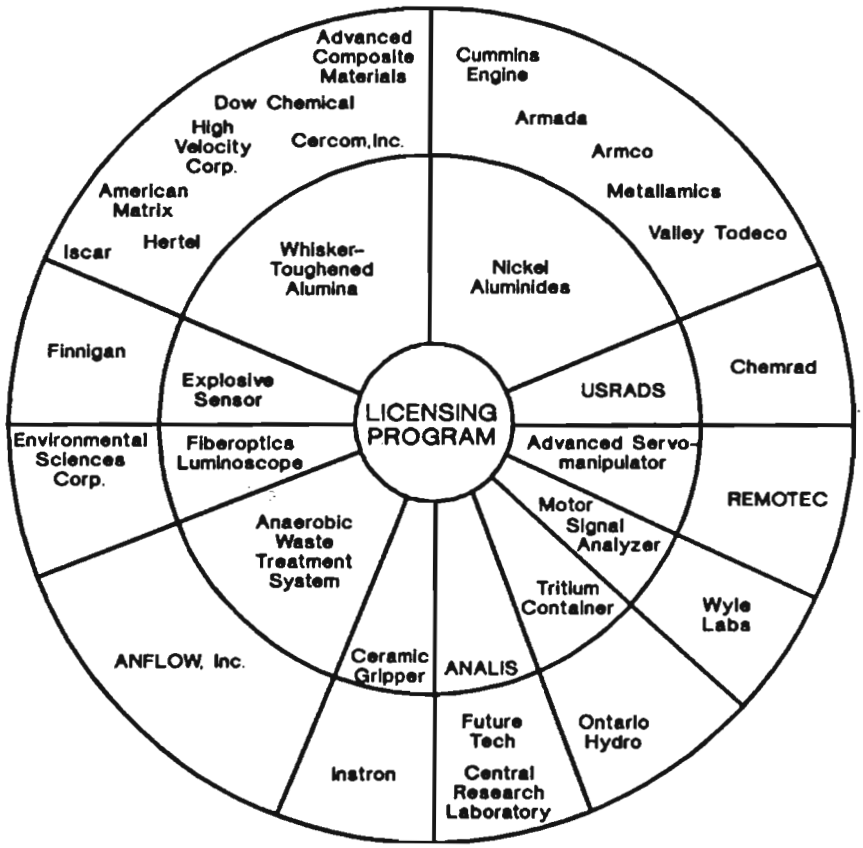


Fig. 25. The ORNL licensing program has produced 24 agreements with 22 firms in 10 technology areas.

Fig. 26. Whisker-toughened ceramics are ceramic-ceramic composites with excellent strength and toughness up to 1200°C and are resistant to both corrosion and thermal shock. These materials may be applied in cutting tools, wear parts, automotive engines, diesel engines, chemical and food processing, and oil field production.

marketed commercially by these firms and is expected to have a significant impact on the billion-dollar-a-year cutting-tool industry.

Using a flexible negotiation approach, Energy Systems offers licensing arrangements to commercial firms that may include various types of protection, up to and including an exclusive agreement, giving the licensee the sole right to manufacture and market the transferred technology.

In many cases, a technology may be licensed to several companies for applications in various fields. This approach was used with the series of modified nickel aluminide alloys recently developed at ORNL (Fig. 27). A license was granted to Cummins Engine Company for use of the alloys in large-displacement diesel engines. Armada Corporation has a license to use the alloys in electrical-resistance heating elements, and Metallamics, Inc., received a license for various tool-and-die and wear applications. Our promotion of this material has been so successful in generating interest among manufacturers that we have recently granted a nonexclusive license to Armco, Inc.

Fig. 27. Nickel aluminides: superalloys for the future. These nickel-based intermetallics are 10–20% lower in density than most superalloys. They gain strength with temperature and are very corrosion-resistant. Nickel aluminides can be produced cheaply and do not depend on strategic materials.

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 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,
- contributing to nonprofit technology transfer organizations, and
- paying federal income taxes.

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.

Encouraging Employee Participation

Many new incentive programs have been established at ORNL to encourage employee participation in the technology transfer program. For example, more than $50,000 has been distributed to inventors for their assistance during the patent application process. Another new practice is sharing 10% of the royalties received (up to a limit of $100,000 per invention) with the inventors. The first royalty distribution, made to seven employee inventors in December 1987,

totaled more than $24,000. A second distribution was made in March 1988, and future distributions will be made as the royalty checks are received from licensees.

Employees who are not named inventors on licensed patents, but who have contributed significantly to our technology transfer program, will receive monetary rewards totaling 4% of the gross royalty receipts. An additional 4% has been set aside to share with inventors of technologies that are considered to be unlicensable but of significant value to the government's missions. A technology may be deemed unlicensable because it is classified, the market is limited to government uses, or the application is too far in the future.

Other incentive measures include establishing an "Inventor of the Year" award to recognize the inventor of the most significant new technology each year, holding an annual patent award luncheon to recognize inventors receiving patents during the year, and forming an internal Inventor's Forum to allow patent-holding employees an opportunity to meet on a regular basis to discuss issues of common concern.

Licensing Accomplishments

The results of these initiatives are worth noting. First, invention disclosures have increased, reversing a 5-year decline. Second, technical publications have also increased, again reversing a 5-year decline. These indicators are even more important because they come at a time when little or no growth has occurred in our R&D budgets.

More than $14.3 million of commercial product sales have resulted from Energy Systems technology licensing efforts (Fig. 28), and nearly $500,000 in license fees and royalties has been received in the past two years (Fig. 29). This encouraging start indicates good prospects for future increases in U.S.-based commercial production from federally funded technologies developed at Oak Ridge.

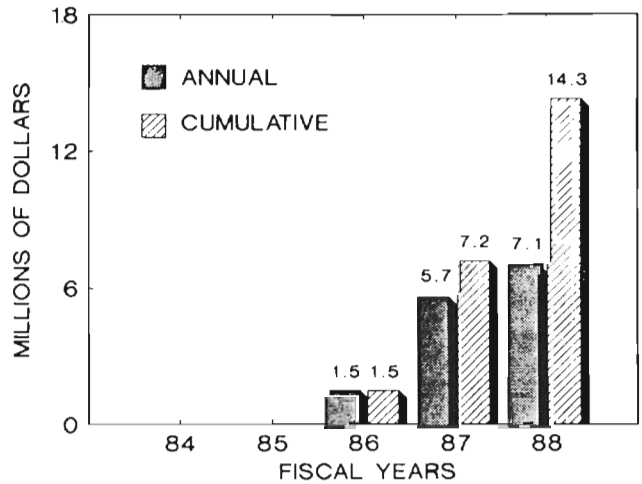


Fig. 28. Product sales achieved (1984–1988).

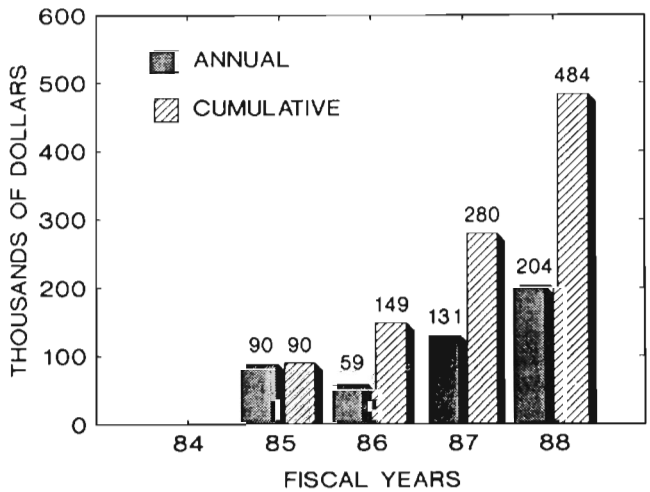


Fig. 29. Royalty income achieved (1984–1988).

Royalty Expenses

The contract between Energy Systems and the U.S. Department of Energy (DOE) specifies how the royalty funds obtained through licensing can be expended. Actual expeditures to date are provided in Fig. 30.

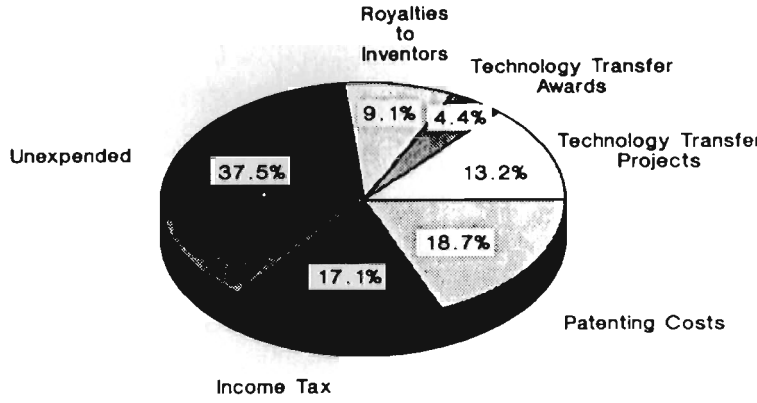


Fig. 30. Expenditures of the royalty funds through FY 1988.

Licensing Goals

Our 5-year goals for technology transfer include developing 50 additional active licenses (Fig. 31), achieving $100 million per year in U.S.-based commercial production from technologies licensed at Oak Ridge (Fig. 32), and generating $4.0 million in annual royalties (Fig. 33).

Every possible effort will be made to accelerate the transfer of Oak Ridge-developed innovations into the commercial sector and to help restore our country's competitive edge in the global marketplace.

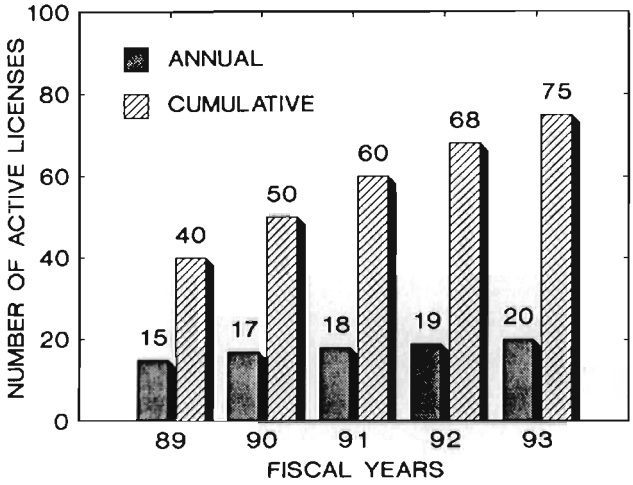


Fig. 31. Licensing objectives (1989–1993).

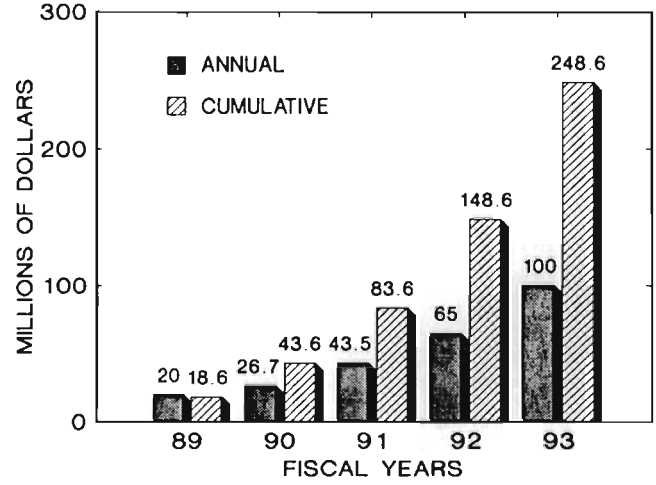


Fig. 32. Product sales objectives (1989–1993).

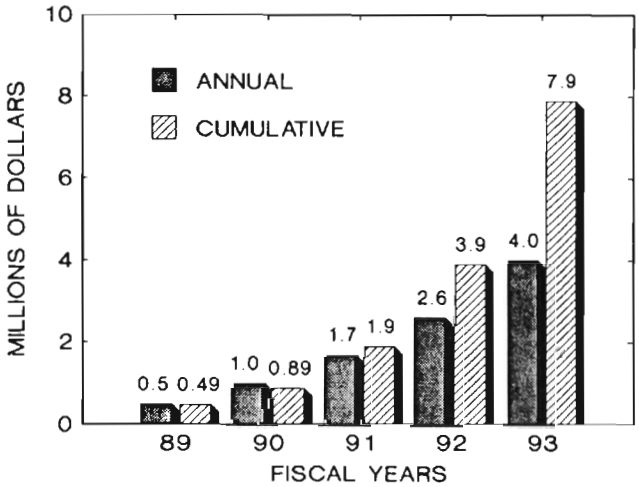


Fig. 33. Royalty income achieved (1989–1993).

Industrial Partnerships

The purpose of developing industry partnerships is to assist in bridging the gap between government R&D and commercialization of the technology developments. The Partnership Development Program accomplishes this by facilitating industry's use of Oak Ridge facilities and expertise. It establishes quality R&D partnerships with individual firms, through industrial R&D consortia, and by assisting new company formations. If the partnerships are established properly, both parties should benefit from the interchange. The following modes of interacting with industry are possible to better access the technologies, facilities, and perhaps most importantly, the expertise available at ORNL:

- guest researchers,
- R&D in user facilities,
- collaborative R&D (jointly funded),
- work-for-others (funds in),
- subcontracts (funds out), and
- consulting with industry.

The mechanism that has the greatest potential for benefiting such industry/national laboratory partnerships is the conduct of collaborative R&D, where both parties make significant contributions to the effort. Industry and national laboratory interactions and increased collaborations between researchers in industrial firms and those in national laboratories will generate new ideas and technologies of value to both types of organization. Most importantly, these cooperative ventures with industry will help integrate the vast technical resources of the federal laboratories into the nation's economy and increase U.S. productivity and competitiveness in today's global economy.

This year's goal is to make substantial progress in removing the administrative barriers so that such agreements are more acceptable to industry and can be executed more rapidly. In the past, several collaborative agreements have been executed, though not with ease. These agreements have demonstrated the potential value of collaborative interactions with industry. For example, Babcock and Wilcox Corporation became interested in applying ORNL's forced chemical vapor infiltration (CVI) technology for producing ceramic composites to manufacturing heat exchanger tubes. ORNL and B&W entered into a 2-year joint development effort in applying CVI technology to ceramic fiber preforms, which were woven together using B&W's proprietary weaving capabilities. Increased U.S. emphasis on the development of technologies to restore global competitiveness and redress the trade imbalance has led ORNL to encourage the formation of additional partnerships between national laboratories and industries.

High-Temperature Superconductivity Pilot Center

The discovery of high-temperature superconductors has inspired new R&D efforts to

capitalize on their technological and economic potential. Technologists are searching for ways of fabricating wires and films, increasing current-carrying capacities, and developing superconducting devices using high-temperature superconducting materials.

To help keep the United States at the forefront of this emerging technology and to secure a competitive edge, DOE has established High-Temperature Superconductivity Pilot Centers at three of its national laboratories: ORNL, Oak Ridge, Tennessee; Argonne National Laboratory (ANL), Chicago, Illinois; and Los Alamos National Laboratory (LANL), Los Alamos, New Mexico. At a press conference announcing the pilot centers, Secretary of Energy John S. Herrington stated that the purpose of these pilot centers is to "make the resources of the federal government available to U.S. industry in developing commercial products from high-temperature conductors."

The three pilot centers are working together with DOE to streamline the process of developing collaborative arrangements with industry and to make terms and conditions for transfer of patent rights and other intellectual property more acceptable. This new approach will enable industries to join more easily in partnerships and to access unique national R&D capabilities with the flexibility to work with one or more laboratories, depending on what best meets a company's needs.

Typical R&D programs in which industries are invited to participate are: synthesis of new superconductors; characterization and analysis of high-temperature superconducting materials, neutron scattering for studying crystalline structures, thin-film superconductors, forming wires and tapes from high-temperature superconducting materials, and improving critical current densities in high-temperature superconductors. The objective of all of these programs is to join with private industry in partnerships to move commercial applications to high-temperature superconductivity more quickly and efficiently into the marketplace. For more information, refer to the "Continuing Initiatives" section of this report.

New Mechanisms for Cooperation

In addition to promoting one-on-one interactions with industry at ORNL, Energy Systems has created mechanisms for consortia of several companies to work together on a technology application in collaboration with ORNL. These mechanisms are most appropriate for cases in which (1) the companies can identify generic technology developments critical to their competitiveness, (2) the risks and capital requirements are too large for a single company to readily undertake, and (3) the national laboratory has strong capabilities that supplement or complement those of industry.

Energy Systems has initiated industrial consortia to expedite the commercialization of R&D results in several areas of national importance such as electronic controls, software development, ceramics, and semiconductors. This type of industry-government cooperation will, in time, contribute significantly to improving our nation's economy and international competitiveness.

Tennessee Center for Research and Development

In 1985, the Tennessee Center for Research and Development (TCRD), a nonprofit corporation, was established on the Technology Corridor (located between Oak Ridge and Knoxville, Tennessee) to derive economic value from the strong science and technology bases of the

region [e.g., ORNL, The University of Tennessee, Knoxville (UTK), and the Tennessee Valley Authority (TVA)]. The TCRD bridges the gap between R&D and commercialization by supporting the development of market-driven applications for new technologies and allowing the consortium sponsors to develop these technologies beyond the capacity of their respective institutions. The TCRD's activities are funded by a variety of sources, including federal and state agencies, industry associations, individual companies, and private investors. The TCRD draws on the R&D resources and capabilities of the sponsoring organizations to accomplish its objectives through various consulting and contractual agreements.

Two organizations that have developed through the TCRD are the Power Electronics Applications Center (PEAC) and the Thermomechanical Model Software Development Center. PEAC has received $6 million of multiyear funding from the Electric Power Research Institute (EPRI). It addresses the power industry's needs for reduced costs, improved efficiencies, and increased quality of electricity use in industrial, commercial, and residential applications. Its objectives are to develop and promote implementation of semiconductor applications for high-voltage and high-current systems to help the United States regain its international competitiveness. Industrial applications include adjustable speed drives, power line conditioners, and uninterruptible power supplies for energy-intensive operations.

The Thermomechanical Model Software Development Center addresses the industry-wide need for easy-to-use models for thermomechanical analysis of refractory systems. It works with complex finite element analysis models and data base developed by the Massachusetts Institute of Technology (MIT) for ORNL (Fossil Energy) to provide user-friendly intelligent front end for the existing system so that industrial design engineers can access system and interpret results. Twelve industrial members have provided $240,000 for funding, to which ORNL adds matching funds.

Partnership Goals

The ORNL goal is to have 30 active industry collaborative agreements, $20 million of funds-in agreements from industry to support R&D at ORNL, and $20 million of cost-shared agreements with industrial partners by FY 1993. These ambitious goals assume some major breakthroughs in the way in which ORNL can do business with industry, which will require a concerted team effort with DOE. Energy Systems management is committed to permitting greater access to ORNL's technologies, facilities, and expertise to assist U.S. industry in its national effort to be more competitive in global markets and to strengthen the U.S. economy.

Designated User Research Facilities

ORNL has served for many years as the steward of numerous, highly sophisticated experimental facilities. These user facilities are designed to jointly serve 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.

Visiting scientists using these facilities are an important source of external interactions for ORNL. In 1988, more than 400 visiting researchers collaborated with ORNL scientists on projects involving user facilities (Table 43). Traditionally, about one-half of these collaborations involve university scientists (Fig. 34), but stronger ties with industry and relaxed patent regulations have prompted a greater number of industrial participants. Figure 35 shows

Table 43. Experimenters at designated user research facilities[a] (FY 1988)

	University	Industry	ORNL	Foreign	Total
En Tandem Van de Graaff	19 (724)	0	14 (491)	6 (46)	39 (1,261)
Holifield Heavy Ion Research Facility (HHIRF)	85 (579)	0	34 (498)	25 (172)	144 (1,249)
Oak Ridge Electron Linear Accelerator (ORELA)	4 (279)	2 (29)	16 (1,669)	2 (13)	24 (1,990)
National Center for Small-Angle Scattering Research (NCSASR)[b]	23 (140)	7 (33)	9 (87)	3 (25)	42 (285)
Neutron Scattering Facility[b]	0	0	0	0	0
Shared Research Equipment (SHaRE)	31 (217)	3 (31)	28 (650)	2 (34)	64 (932)
Surface Modification and Characterization (SMAC) Laboratory	36 (349)	10 (17)	40 (1,165)	6 (68)	92 (1,599)
Bioprocessing Research Facility	6 (79)	1 (2)	0	2 (95)	9 (176)
Health Physics Research Reactor[b] (HPRR)	0	0	0	0	0
National Environmental Research Park (NERP)	62 (1,495)	3 (69)	43 (1,341)	1 (1)	109 (2,906)
Roof Research Facility	1 (1,680)	1 (15)	0	0	2 (1,695)
High Temperature Materials Laboratory (HTML)	13 (68)	9 (80)	94 (929)	0	116 (1,077)
Total (12 facilities):	280 (5,610)	36 (276)	278 (6,830)	47 (454)	641 (13,170)

[a]Number of users is provided; number of user-days is in parentheses.
[b]Facility affected by DOE reactor shutdown order.

trends in the number of outside users of our facilities since 1979. The use of user facilities is expected to increase as ORNL seeks greater interaction and collaboration with other research organizations and industries.

A major factor influencing the use of user facilities in FY 1987 and 1988 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),

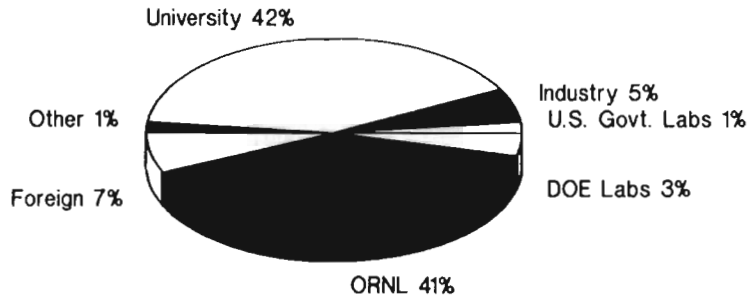


Fig. 34. Participants at ORNL user facilities (FY 1988).

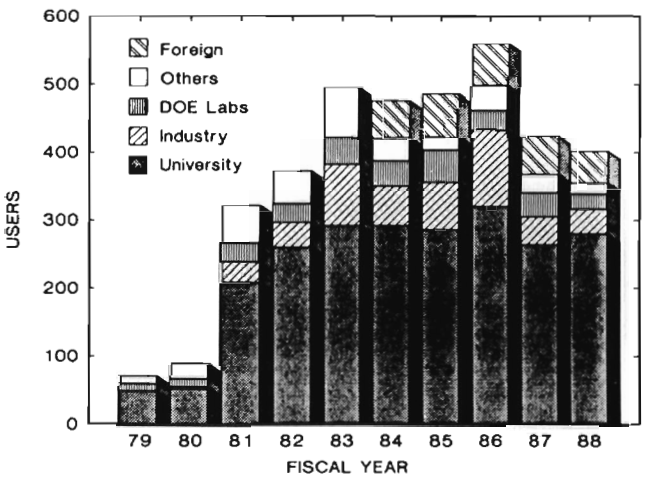


Fig. 35. Number of outside users of ORNL facilities.

- 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, leaving 12 ORNL scientific facilities designated as official user facilities.

User facilities will play a key role in future energy research for the United States; therefore, the associate director of ORNL research reactors and his staff are working to return these reactor facilities to operation as safely and quickly as possible.

University Programs

Educational Programs

Overview of ORNL's University Relations Programs

The DOE University Laboratory Cooperative Program (ULCP), Office of Energy Research (OER), 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 1000 university-based researchers are housed 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. Over 1000 annual guests at ORNL are affiliated with universities, either as precollege students, undergraduate and graduate students, faculty, or postgraduate appointees. Most 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 400 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 on research participation appointments;
- donating and loaning 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 the Office of University Relations 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. Recently, 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 (HASRD). Over the two decades that ORNL has hosted undergraduate students on academic-year science semester programs, students have made substantive contributions to ORNL projects that later were patented and/or received I•R 100 awards. Furthermore, working with university personnel fulfills the Laboratory's technology transfer objectives.

Over 20 different programs provide opportunities for students and faculty to participate in research at ORNL for appointment periods ranging from 6 weeks to several years. About half the programs are administered through ORAU. Opportunities exist for summer and/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 105 co-op students were employed by ORNL in FY 1988; by contrast, about 200 students, 48 postgraduates, and 30 faculty received research-participation appointments through programs run by the Office of University Relations. These appointments exclude the almost 200 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 historically black colleges and universities (HBCU) 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 moved closer to the Southeastern Universities Research Association (SURA), which is another consortium of major universities in the Southeast, through such activities as membership on the Board of Trustees and various committees. ORNL also continues to have strong semester programs with the Great Lakes Colleges Association/Associated Colleges of the Midwest (GLCA/ACM) and Southern College University Union (SCUU) consortia, now both in their second decades.

Research and Development Subcontracts

ORNL awards about 270 R&D subcontracts to over 100 universities annually. These subcontracts generally sponsor research on campus, but may also include provisions for student internships or faculty appointments to perform research at the Laboratory. About 40% of ORNL's subcontract obligations are with 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. Money committed through subcontracts to minority education institutions has increased by over 25% during the second half of FY 1988. Program HA is the largest sponsor of university subcontracts, accounting for about 18% in FY 1986. Other major sponsors of university research are Program EB (16%), Program EE (13%), and Program AA (10%). A large percentage (over 45%) of the university subcontracts are 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 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.

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 (ERLE) 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. The Laboratory maintains a data base, which is updated monthly, that lists available equipment. University personnel can access this data base.

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 (IRI) 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 12 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. Of the non-ORNL participants using these facilities over the last 5 years, about 60% came from universities.

In FY 1988, nearly 300 university researchers performed experiments for 5610 user days in ORNL's DOE user facilities. The largest percentage of the university-based users (31%) perform research at the Holifield Heavy Ion Research Facility. 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 (ORR), is one of the best sites in the world for watershed research. Arrangements to use these resources are made directly with research staff or through the Office of University Relations.

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 is 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 Relations. University Relations 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 many years several programs have existed to avail the Laboratory to high school students and teachers. In the summer of 1985, 14 high school teachers 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 Carbon Dioxide program and the High School Honors Workshop, were implemented during FY 1988. The Carbon Dioxide program is a national program involving teachers concerned with research about the global carbon cycle and with linking this research to curriculum development. Teachers were also involved as science associates with the High School Honors Workshop, serving as liaisons between the students and ORNL science staff.

In FY 1988, 28 teachers participated in research activities at ORNL under the management of the University Relations Office. A teacher 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 1988, PRISM Associate Teachers (PAT), 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.

Programs established for high school students have been expanded and new programs have been implemented. ORNL hosted one of the DOE National High School Honors Workshops in FY 1988, with a focus on environmental sciences. Over 100 Environmental Sciences Division (ESD) 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, France, 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 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. Seven students participated in the

program in FY 1988, for a total of 12 participants since the inception of the program.

Initiatives are also being developed to involve minorities in precollege programs in an effort to increase the pool of minority 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. It is expected to reach a participation level of five in FY 1989. In addition, the "Challenge" program, designed to encourage and prepare minorities for careers in science and related fields, involved staff from the Office of University Relations in FY 1988.

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 18 study modules that provide students with the opportunity for hands-on learning in both the life sciences and physical sciences. The units are offered generally as half-day field activities and are tailored for the academic level of elementary, junior high, or senior high school students. The Study Center now operates year-round, including Summer Science Saturdays for adult community members and children. Since its inception in 1983, the Study Center has hosted over 8000 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 "handicapable" 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 "handicapable" individuals.

A partnership with the Oak Ridge schools has been developed and implementation has begun to link 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

Several undergraduate student programs are worth mentioning in more detail because of their popularity, uniqueness, or newness. The Technology Internship Program (TIP) provides training opportunities for students pursuing an associate degree. Although the program is only 4 years old, most of the participants have already been hired for regular employment as technicians. The Student Research Participation program brings in students during the summer between their junior and senior years for 10-week appointments. Many of these students are subsequently hired for summers during graduate school under the ORNL Summer Research Internship program.

The Oak Ridge Science Semester program, almost two decades old, is an academic-year research participation program. Selected upperclass students who attend colleges belonging to GLCA/ACM and SCUU spend one semester at ORNL performing research and taking courses taught by resident faculty from the consortia, for which they receive academic credit. A 10-year survey of the GLCA/ACM program indicated that over 90% of the participants had received a

graduate degree or were currently enrolled in graduate school.

The Special Summer Program provides opportunities for undergraduate students from HBCUs to participate in research as early as the freshman year, with the intention to rehire for subsequent summers through graduation. Because of this program, and other university-relations programs, the number of participants from minority educational institutions has increased significantly over the last two fiscal years. The number of students and faculty from HBCUs has climbed from 4 in FY 1985 to 29 in FY 1988, and the number of students and faculty from Hispanic institutions was increased from none in FY 1985 to 19 in FY 1988.

Graduate Programs

Graduate students can perform prethesis research through several programs. ORNL has hosted a number of students for summer practicum experience who have been awarded DOE fellowships. Thesis research, which can be sponsored by ORNL R&D subcontracts, is also the objective of the Laboratory Graduate Participation (LGP) program. Students selected for this program perform full-time thesis or dissertation research for up to 2 years under the direction of his or her graduate committee, which would include both ORNL and university representatives. This program is very competitive and selective; typically fewer than ten appointments are made annually.

All candidates must be approved by the ORNL Graduate Fellow Selection Panel, a committee composed of professional staff representing all ORNL research and technical divisions. The ORNL Graduate Fellow Selection Panel also is responsible for approving students with masters degrees and postdoctoral applicants who are appointed through the Postgraduate Research Training/Appointment programs. Also highly competitive and selective, this program allows ORNL staff the opportunity to receive valuable program assistance from recent graduates desiring further research experience. Special attention is paid to specific programmatic needs. Laboratory employees have been recruited from graduate student programs. For example, the Summer Research Internship program is designed for graduate students with a minimum grade-point average of 3.5. Students enrolled in health physics graduate programs were actively recruited; four were hired as interns for summer 1986. In addition to the health physics interns, graduate students have also been recruited specifically to assist with activities in the national Hazardous Waste Remedial Actions Program (HAZWRAP).

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. Three Distinguished Scientists began appointments in FY 1988. 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 program in biotechnology and a graduate program in measurement and control engineering.

The UTK Graduate Programs at ORNL

Perhaps the least known, yet strongest ORNL-UTK joint programs are the two UTK graduate schools located at ORNL. The Oak Ridge Graduate School of Biomedical Sciences (ORGSBS) and the Graduate Program in Ecology are both in their second decade. Both graduate programs at ORNL 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 ESD. Similar to ORGSBS, the Ecology program offers full-time graduate study for M.S., Ph.D., and postdoctoral students. The students are largely supported by ESD programmatic funding. About 20% of the research training is provided by ESD staff, who also teach courses under adjunct appointments. Enrollment is typically about 15 graduate and postgraduate students.

Minority Institutions

On January 19, 1988, ORNL and DOE signed an MOU with Southern University. The MOU was initiated to formalize joint program activities that will assist Southern University in enhancing its research and educational capabilities and assist DOE in achieving its missions. Subcontracts are in process in the amount of $245,000, which includes two subcontracts with the Y-12 Plant.

On September 23, 1988, ORNL and DOE also signed an MOU with the University of Puerto Rico (UPR). A Field Work Proposal was submitted requesting funding for various collaborative ventures for a period of 3 years to augment existing initiatives involving UPR students and faculty in environmental science research.

FY 1988 was a year of significant expansion for the program. Over 30 students and faculty members spent summer internships at ORNL and the Y-12 Plant. Subcontract commitments increased nearly 40% from FY 1987 commitments, even as total commitments in subcontract awards to higher educational institutions (HEIs) decreased by over 15%. FY 1988 subcontract commitments to minority educational institutions (MEIs) was $1.4 million. This represented 8.2% of the total subcontract commitments to HEIs being received by MEIs.

Efforts continue to identify excess equipment that might be used on MEI campuses toward enhancing their research capabilities. During FY 1988, through various interactions with MEI faculty, over $112 thousand worth of equipment was loaned to four MEIs. Also during FY 1988,

efforts were made to establish new Field Work Proposals (FWPs) to provide continuity of funding of subcontracts beyond one year with selected MEIs; toward this end, 11 FWPs were established with projected award commitments of over $3.3 million through FY 1991.

In April 1987, Energy Systems appointed an MEI Program Manager under the direction of the Energy Systems Director of Minority Program Development to act as the focal point for Energy Systems involvement with HBCUs. Because most of the MEI/Energy Systems interactions take place with ORNL, the MEI Program Office is located in the ORNL Office of University Relations.

The main thrust of the program is to develop opportunities through internal (Energy Systems) and external (MEI) 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 also under way with other minority educational institutions including UPR, New Mexico Highlands University, and the Ana G. Méndez Educational Foundation (AGMEF). Energy Systems is also working with ORAU, the Southeastern Consortium for Minorities in Engineering (SECME), and various precollege school systems seeking to increase the number of minorities and women who elect science and engineering programs in college.

Several new initiatives in support of precollege and minority programs are expected to be funded by the KE program next year. These new initiatives include the following.

- With Oak Ridge serving as the lead laboratory in partnership with seven other participating DOE laboratories, a National Science Foundation (NSF) grant proposal for a multilaboratory teacher training program for teachers in grades K–8 has been submitted.
- Several national teacher training programs are expected to be expanded and/or modified in FY 1989. The newly initiated Carbon Dioxide program, with emphasis on curriculum development in the area of carbon dioxide, is expected to expand to a level of 15 participants; the reorganized national high school teacher enrichment program, formerly known as REST, is expected to involve another 15–20 teachers doing research during the summer of 1989.
- MOUs with UPR and with the Science and Technology Alliance were signed in 1988, with resulting plans to expand collaborations with the represented institutions through increased student and faculty research participation as well as through the support of faculty and ORNL staff visitations. Precollege programs and joint research projects are 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 are being developed that involve efforts to provide activities for females and other under-represented minorities, to enhance mathematics education, to strengthen precollege education in the physical sciences, and to provide academic-year activities to revitalize teachers and students.

Proposed Programs

In its efforts to increase interactions with premier academic institutions, ORNL has established an MOU with Duke University. ORNL is also expanding its interactions with the service academies through the Service Academy Research Associates (SARA) program. Increasing numbers of students from the Naval Academy, West Point, and, for the first time, students from the Air Force Academy will participate in the

SARA program. Faculty from the service academies will also be encouraged to participate.

The number of university research participants is expected to increase in FY 1989 with the continuation of the Oak Ridge Science and Engineering Research Semesters. When fully operational, the Oak Ridge Science and Engineering Research Semester program would support over 300 students annually for research participation and training, mostly during the academic year. All participants will be housed in a multipurpose building to be constructed in central Oak Ridge. The program is being successfully phased in with over 60 participants in FY 1988.

Summary

The precollege and university relations programs will continue to grow significantly in the future. It is important that a facility be developed that meets the needs of our growing precollege and university programs. ORNL will continue to involve new groups in our activities, implement new programs to meet needs, and otherwise enhance our education and training activities. The catalog of programs currently offered by ORNL is considerable and impressive, but opportunities for new initiatives still exist.

The ORNL University Relations program will continue to grow and act as a model for other federal laboratories and corporate entities in their efforts to enhance the education of the nation's youth. ORNL has demonstrated a commitment to increase the involvement of university personnel in its R&D activities. It is imperative to supply well-trained, qualified technical personnel for the future. The Laboratory is assisting DOE in achieving this goal in two ways: (1) by providing opportunities for students of all ages to receive training and to perform research and (2) by encouraging students to attend graduate school in energy-related disciplines. The university interactions are also important in transferring science and technology through sponsoring faculty research participation and visits at ORNL and through ORNL staff visits and lectures on campus. Collaborative research programs with university personnel will continue to be a cost-effective method to receive quality assistance in fulfillment of the Laboratory's missions.

A proposal has been submitted to the NSF for a teacher-enhancement program for teachers from kindergarten through grade 8. This multilaboratory proposal involves eight DOE laboratories, with ORNL serving as the lead laboratory. The proposal calls for a budget of nearly $6 million over a 5-year period and is expected to serve over 400 teachers. The teacher program will focus on "hands-on" activities that link the "big science" of the laboratory to conventional science curricula.

Minority Business Procurement

Energy System's Award Fee Contract with DOE requires that we provide maximum practical opportunity for minority businesses to sell us the commodities and services used in the operation of our facilities and programs.

ORNL management and staff work closely with the Socioeconomic Programs Office and Purchasing staffs to identify and qualify companies owned by socially and economically disadvantaged individuals to participate in the company's purchasing activities. The following activities support this program.

- Outreach—more than 25 trade shows, business opportunity fairs, and conferences for small and disadvantaged businesses are attended each year. Staff members also meet one-on-one with minority companies to enable them to "market" their goods and services.
- Seminars and workshops are cosponsored with DOE and other organizations to help company representatives better understand our

requirements and the correct procedures for doing business with us.

- Large, complex procurements are broken down into smaller pieces to enable greater participation from minority firms.
- Special arrangements are made with Accounts Payable to ensure that prompt payment is made to minority firms to help alleviate cash-flow problems.
- An annual awards program is conducted that recognizes a minority-owned firm and minority colleges or universities for outstanding performance of work for us.
- As part of the awards activity discussed previously, internal staff are recognized for their support of the program by serving as "advocates" for small and disadvantaged companies.
- Strong support is provided to DOE in identifying work that can be awarded to minority companies that have been certified under the Small Business Administration's 8(a) Program. Once the award is placed by DOE, our staff members serve as technical monitors for the contracts.

Placement of contracts and orders with minority companies has increased steadily over the years. Energy Systems has received the following awards recognizing performance in this area.

- FY 1988—Distinguished Prime Contractor of the Year for Region IV—awarded by SBA-Headquarters;
- FY 1988—Small Minority Business Advocate of the Year for the state of Tennessee, Ruby Miller—awarded by SBA-Region IV;
- FY 1988—Corporation of the Year, Portsmouth Gaseous Diffusion Plant—awarded by Columbus (Ohio) Regional Minority Suppliers' Development Council; and
- FY 1987—Small and Minority Business Advocate award, Allyn Zerby of C&TD at ORNL.

Appendix: Resource Projections

Table A.1. Laboratory funding summary

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

	Fiscal year						
	1988	1989	1990	1991	1992	1993	1994
DOE	319.81	319.56	380.85	396.71	431.59	432.30	408.88
Work for Others[b]	103.64	105.01	118.81	119.08	109.61	110.15	111.01
Total operating	423.45	424.57	499.66	515.79	541.20	542.45	519.89
Capital equipment	17.01	20.23	25.97	24.27	23.53	23.91	23.97
Program construction							
Funded/budgeted	11.89	11.70	13.30	5.20			
Proposed		0.72	2.33	25.83	74.20	76.00	109.21
General-Purpose Facilities							
Funded/budgeted	9.24	2.91					
Proposed[c]		1.65	9.00	10.50	11.00	11.00	11.00
General Plant Projects (AT, GF, KG)	9.81	16.05	9.50	10.50	10.50	10.50	10.50
General Purpose Equipment (AT, KG)	3.80	3.81	10.30	10.30	10.30	10.30	10.30
Total Laboratory	475.20	481.64	570.06	602.39	670.73	674.16	684.87

[a]4.5% escalation from 1988–1989 and 1989–1990. 1990–1994 = constant 1990 dollars.
[b]Includes Nuclear Regulatory Commission.
[c]Proposed funding levels reflect budget guidance rather than actual Laboratory needs.

Table A.2. Laboratory personnel summary

	Fiscal year						
	1988	1989	1990	1991	1992	1993	1994
DOE	1309.6	1348.6	1376.9	1396.9	1393.9	1401.4	1415.3
Work for Others[a]	327.1	372.6	401.4	409.3	408.6	409.0	411.6
Isotopes program	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Total technical direct	1672.7	1757.2	1814.3	1842.2	1838.5	1846.4	1862.9
Other direct	325.9	368.0	380.0	377.9	352.9	355.4	359.7
Total direct personnel	1998.6	2125.2	2194.3	2220.1	2191.4	2201.8	2222.6
Indirect personnel	2218.4	2359.0	2435.7	2464.3	2432.5	2444.0	2467.1
Total Laboratory	4217.0	4484.2	4630.0	4684.4	4623.9	4645.8	4689.7

[a]Includes Nuclear Regulatory Commission.

Table A.3. Funding by assistant secretarial level office

($ in millions)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Assistant Secretary for Fossil Energy														
Total operating	6.68	7.54	7.35	8.49	7.83	8.64	7.95	8.34	7.90	7.90	7.90	7.90	7.90	7.90
Capital equipment	0		0.44		0.77		0.32		0.32		0.32		0.32	
Total	6.68		7.80		8.61		8.27		8.22		8.22		8.22	
Assistant Secretary for Nuclear Energy														
Total operating	40.53	36.95	33.53	32.52	32.60	32.51	34.20	34.09	32.41	32.25	32.27	32.57	31.36	31.66
Capital equipment	2.02		3.71		3.03		3.28		3.53		3.88		3.90	
Total	42.55		37.23		35.63		37.48		35.94		36.16		35.26	
Assistant Secretary for Conservation and Renewable Energy														
Total operating	43.87	42.59	48.31	49.28	51.32	51.39	52.83	51.68	52.78	51.89	52.78	51.89	52.78	51.93
Capital equipment	0.73		2.09		2.48		2.25		2.25		2.25		2.25	
Total	44.60		50.39		53.80		55.08		55.03		55.03		55.03	
Assistant Secretary for International Affairs and Energy Emergencies														
Total operating	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0
Office of Energy Research														
Total operating	158.25	164.06	160.70	162.11	172.58	172.70	171.77	171.76	172.93	172.92	174.82	174.82	177.78	177.78
Capital equipment	15.78		13.51		24.88		25.34		24.50		24.49		24.48	
Funded construction	28.30		21.30		13.30		5.45		0		0		0	
Total	202.33		195.51		210.76		202.56		197.43		199.31		202.26	
Assistant Secretary for Defense Programs														
Total operating	31.42	30.83	34.84	34.88	80.84	80.85	94.33	93.83	128.33	127.83	127.19	126.69	103.13	102.62
Capital equipment	1.45		1.50		3.91		2.94		2.90		2.93		2.99	
Funded construction	4.40		0		0		0		0		0		0	
Total	37.28		36.34		84.75		97.27		131.23		130.11		106.12	
Assistant Secretary for Environment, Safety, and Health														
Total operating	8.10	8.84	6.00	6.74	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Capital equipment	0.13		0.05		0.07		0.05		0.05		0.05		0.05	
Total	8.23		6.05		6.06		6.05		6.05		6.05		6.05	
Federal Energy Regulatory Commission														
Total operating	0.09	1.43	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Economic Regulatory Administration														
Total operating	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0

Table A.3 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Energy Information Administration														
Total operating	1.07	1.68	1.50	1.75	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Office of Policy, Planning, and Analysis														
Total operating	0.22	0.23	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Office of Civilian Radioactive Waste Management														
Total operating	11.09	9.64	10.93	10.95	10.91	10.91	11.01	11.01	11.01	11.01	11.01	11.01	11.01	11.01
Capital equipment	0.01		0.06		0.02		0.02		0.02		0.02		0.02	
Total	11.10		10.99		10.93		11.03		11.03		11.03		11.03	
Assistant Secretary for Management and Administration														
Total operating	0.34	0.24	0.12	0.23	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Subtotal DOE Programs														
Total operating	301.66	304.07	303.83	307.50	364.51	365.42	380.52	379.15	413.80	412.23	414.41	413.30	392.40	391.34
Capital equipment	20.11		21.36		35.16		34.20		33.55		33.93		34.00	
Funded construction	32.70		21.30		13.30		5.45		0.00		0.00		0.00	
Total	354.47		346.49		412.97		420.17		447.35		448.34		426.40	
DOE Contractors and Operations Offices														
Total operating	18.15	15.84	15.72	16.29	16.35	16.35	16.19	15.75	17.79	17.79	17.89	17.89	16.49	16.49
Capital equipment	0		1.36		0		0		0		0		0	
Total	18.15		17.08		16.35		16.19		17.79		17.89		16.49	
Total DOE Programs														
Total operating	319.81	319.91	319.56	323.79	380.85	381.77	396.71	394.90	431.59	430.02	432.30	431.19	408.88	407.82
Capital equipment	20.11		22.72		35.16		34.20		33.55		33.93		34.00	
Funded construction	32.70		21.30		13.30		5.45		0		0		0	
Total DOE Programs	372.63		363.57		429.31		436.36		465.15		466.23		442.89	
Work for Others														
Department of Defense														
Total operating[b]	14.73	14.73	30.92	30.92	37.56	37.56	39.64	39.64	40.00	40.00	40.00	40.00	40.30	40.30
Capital equipment	0.38		0.15		0.15		0.15		0.15		0.15		0.15	
Total	15.11		31.07		37.71		39.79		40.15		40.15		40.45	
Department of Defense Data Systems														
Total operating[b]	34.80	21.02	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00

Table A.3 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Other Agencies Data Systems														
Total operating[b]	0.89	0.88	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Hazardous Waste Research and Development														
Total operating[b]	8.79	6.18	6.50	6.50	7.50	7.50	8.00	8.00	8.50	8.50	9.00	9.00	9.50	9.50
Capital equipment	0.10		0.06		0.05		0.05		0.05		0.05		0.05	
Total	8.89		6.56		7.55		8.05		8.55		9.05		9.55	
Department of Transportation														
Total operating[b]	0.40	0.42	0.51	0.51	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Federal Emergency Management Agency														
Total operating[b]	1.67	2.16	2.00	2.26	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
Nuclear Regulatory Commission														
Total operating[b]	14.64	14.44	14.63	14.60	16.26	16.26	16.26	16.26	16.28	16.28	16.32	16.32	16.38	16.38
Capital equipment	0.15		0.04		0.02		0.02		0.02		0.02		0.02	
Total	14.80		14.67		16.28		16.28		16.30		16.34		16.40	
Department of Health and Human Services														
Total operating[b]	5.28	5.28	5.30	5.30	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50
Environmental Protection Agency														
Total operating[b]	4.74	4.74	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Capital equipment	0.06		0.05		0.05		0.05		0.05		0.05		0.05	
Total	4.80		5.05		5.05		5.05		5.05		5.05		5.05	
National Science Foundation														
Total operating[b]	1.16	1.16	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Tennessee Valley Authority														
Total operating[b]	0.94	0.94	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Other federal agencies														
Total operating[b]	9.15	8.31	14.64	14.67	18.91	18.95	16.63	16.67	6.28	6.31	6.28	6.31	6.28	6.31
Capital equipment	0		1.02		0.84		0.10		0		0		0	
Total	9.15		15.66		19.76		16.73		6.28		6.28		6.28	
Electric Power Research Institute														
Total operating[b]	4.64	4.64	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Table A.3 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Other Nonfederal Agencies														
Total operating[b]	1.79	1.94	2.13	2.13	1.83	1.83	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81
Total Work for Others														
Total operating[b]	103.64	86.85	105.01	105.27	118.81	118.84	119.08	119.11	109.61	109.64	110.15	110.18	111.01	111.04
Capital equipment	0.69		1.32		1.11		0.37		0.27		0.27		0.27	
Total Work-for-Others programs	104.33		106.33		119.92		119.45		109.88		110.42		111.28	
Total Laboratory														
Total operating[b]	423.45	406.75	424.56	429.07	499.66	500.61	515.79	514.02	541.20	539.66	542.45	541.37	519.89	518.87
Capital equipment	20.81		24.04		36.27		34.57		33.82		34.20		34.27	
Funded construction	32.70		21.30		13.30		5.45		0		0		0	
Total	476.96		469.90		549.23		555.81		575.02		576.65		554.17	

[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 1994 are in constant FY 1991 dollars.
[b] Includes subcontracts and funds for required support from other sites.

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
Assistant Secretary for Fossil Energy							
Technical personnel	24.8	30.6	33.9	30.2	30.9	30.9	30.9
Other direct personnel	1.8	0.9	1.1	1.0	1.0	1.0	1.0
Total direct personnel	26.6	31.5	35.0	31.2	31.9	31.9	31.9
Assistant Secretary for Nuclear Energy							
Technical personnel	171.2	177.5	172.2	172.9	167.6	168.0	163.9
Other direct personnel	10.0	8.5	9.5	16.9	5.4	5.4	4.4
Total direct personnel	181.2	186.0	181.7	189.8	173.0	173.4	168.3
Assistant Secretary for Conservation and Renewable Energy							
Technical personnel	120.1	144.6	149.1	149.3	149.3	149.3	149.4
Other direct personnel	8.6	2.1	2.1	2.1	2.1	2.1	2.1
Total direct personnel	128.7	146.7	151.2	151.4	151.4	151.4	151.5
Assistant Secretary for International Affairs and Energy Emergencies							
Technical personnel	0	0	0	0	0	0	0
Other direct personnel	0	0	0	0	0	0	0
Total direct personnel	0	0	0	0	0	0	0
Office of Energy Research							
Technical personnel	705.1	713.6	712.5	712.6	718.9	723.6	739.1
Other direct personnel	212.6	218.0	217.0	207.6	209.3	210.3	213.8
Total direct personnel	917.7	931.6	929.5	920.2	928.2	933.9	952.9
Assistant Secretary for Defense Programs							
Technical personnel	129.0	129.6	169.0	190.7	186.0	188.4	190.8
Other direct personnel	7.7	41.1	44.4	49.0	39.1	39.3	39.7
Total direct personnel	136.7	170.7	213.4	239.7	225.1	227.7	230.5
Assistant Secretary for Environment, Safety, and Health							
Technical personnel	36.5	27.0	22.0	22.0	22.0	22.0	22.0
Other direct personnel	4.2	3.0	3.0	3.0	3.0	3.0	3.0
Total direct personnel	40.7	30.0	25.0	25.0	25.0	25.0	25.0
Federal Energy Regulatory Commission							
Technical personnel	6.7	1.5	1.5	1.5	1.5	1.5	1.5
Other direct personnel	0.1	0	0	0	0	0	0
Total direct personnel	6.8	1.5	1.5	1.5	1.5	1.5	1.5

Table A.4 (continued)

	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	FY 1994
Economic Regulatory Administration							
Technical personnel	0	0	0	0	0	0	0
Other direct personnel	0	0	0	0	0	0	0
Total direct personnel	0	0	0	0	0	0	0
Energy Information Administration							
Technical personnel	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Other direct personnel	0	0	0	0	0	0	0
Total direct personnel	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Office of Policy, Planning, and Analysis							
Technical personnel	0.4	1.1	1.0	1.0	1.0	1.0	1.0
Other direct personnel	0.1	0	0	0	0	0	0
Total direct personnel	0.5	1.1	1.0	1.0	1.0	1.0	1.0
Office of Civilian Radioactive Waste Management							
Technical personnel	29.3	39.6	38.1	39.1	39.1	39.1	39.1
Other direct personnel	8.4	11.0	11.7	12.0	12.0	12.0	12.0
Total direct personnel	37.7	50.6	49.8	51.1	51.1	51.1	51.1
Assistant Secretary for Management and Administration							
Technical personnel	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Other direct personnel	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total direct personnel	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Subtotal DOE Programs							
Technical personnel	1225.9	1268.0	1302.2	1322.2	1319.2	1326.7	1340.6
Other direct personnel	253.8	284.9	289.1	291.9	272.2	273.4	276.3
Total direct personnel	1479.7	1552.9	1591.3	1614.1	1591.4	1600.1	1616.9
DOE Contractors and Operations Offices							
Technical personnel	83.7	80.6	74.7	74.7	74.7	74.7	74.7
Other direct personnel	15.3	15.3	16.8	15.8	15.8	15.8	15.8
Total direct personnel	99.0	95.9	91.5	90.5	90.5	90.5	90.5
Total DOE Programs							
Technical personnel	1309.6	1348.6	1376.9	1396.9	1393.9	1401.4	1415.3
Other direct personnel	269.1	300.2	305.9	307.7	288.0	289.2	292.1
Total direct personnel	1578.7	1648.8	1682.8	1704.6	1681.9	1690.6	1707.4

Table A.4 (continued)

	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	FY 1994
Work for Others							
Department of Defense							
Technical personnel	72.8	113.9	136.6	146.8	148.0	146.3	145.6
Other direct personnel	8.7	10.1	17.3	18.3	17.9	18.8	19.8
Total direct personnel	81.5	124.0	153.9	165.1	165.9	165.1	165.4
Department of Defense Data Systems							
Technical personnel	35.1	35.0	35.0	35.0	35.0	35.0	35.0
Other direct personnel	14.0	10.0	10.0	10.0	10.0	10.0	10.0
Total direct personnel	49.1	45.0	45.0	45.0	45.0	45.0	45.0
Other Agencies' Data Systems							
Technical personnel	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Other direct personnel	0	0	0	0	0	0	0
Total direct personnel	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Hazardous Waste Research and Development							
Technical personnel	28.5	30.0	38.0	38.0	40.0	42.0	45.0
Other direct personnel	3.4	5.4	6.2	6.6	7.1	7.5	7.9
Total direct personnel	31.9	35.4	44.2	44.6	47.1	49.5	52.9
Department of Transportation							
Technical personnel	1.4	2.2	2.2	2.2	2.2	2.2	2.2
Other direct personnel	0	0	0	0	0	0	0
Total direct personnel	1.4	2.2	2.2	2.2	2.2	2.2	2.2
Federal Emergency Management Agency							
Technical personnel	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Other direct personnel	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Total direct personnel	10.4	10.4	10.4	10.4	10.4	10.4	10.4
Nuclear Regulatory Commission							
Technical personnel	65.0	60.0	60.6	60.6	60.6	60.7	61.0
Other direct personnel	9.3	10.6	12.5	12.5	12.5	12.5	12.5
Total direct personnel	74.3	70.6	73.1	73.1	73.1	73.2	73.5
Department of Health and Human Services							
Technical personnel	34.1	34.0	34.0	34.0	34.0	34.0	34.0
Other direct personnel	0.3	0.5	0.5	0.5	0.5	0.5	0.5
Total direct personnel	34.4	34.5	34.5	34.5	34.5	34.5	34.5

Table A.4 (continued)

	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	FY 1993	FY 1994
Environmental Protection Agency							
Technical personnel	21.5	22.0	22.0	22.0	22.0	22.0	22.0
Other direct personnel	0.3	1.0	1.0	1.0	1.0	1.0	1.0
Total direct personnel	21.8	23.0	23.0	23.0	23.0	23.0	23.0
National Science Foundation							
Technical personnel	5.8	7.0	7.0	7.0	7.0	7.0	7.0
Other direct personnel	0	0.5	0.5	0.5	0.5	0.5	0.5
Total direct personnel	5.8	7.5	7.5	7.5	7.5	7.5	7.5
Tennessee Valley Authority							
Technical personnel	3.6	4.0	4.0	4.0	4.0	4.0	4.0
Other direct personnel	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total direct personnel	4.6	5.0	5.0	5.0	5.0	5.0	5.0
Other Federal Agencies							
Technical personnel	26.0	29.2	28.3	26.3	22.4	22.4	22.4
Other direct personnel	16.5	25.0	22.1	16.1	10.7	10.7	10.7
Total direct personnel	42.5	54.2	50.4	42.4	33.1	33.1	33.1
Electric Power Research Institute							
Technical personnel	14.6	15.0	15.0	15.0	15.0	15.0	15.0
Other direct personnel	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Total direct personnel	15.2	15.5	15.5	15.5	15.5	15.5	15.5
Other Nonfederal Agencies							
Technical personnel	8.6	10.3	8.7	8.4	8.4	8.4	8.4
Other direct personnel	0.3	0.8	0.8	0.8	0.8	0.8	0.8
Total direct personnel	8.9	11.1	9.5	9.2	9.2	9.2	9.2
Total Work for Others							
Technical personnel	327.1	372.6	401.4	409.3	408.6	409.0	411.6
Other direct personnel	56.8	67.8	74.8	70.2	64.9	66.2	67.6
Total direct personnel	383.9	440.4	476.2	479.5	473.5	475.2	479.2
Total Laboratory							
Technical personnel	1636.7	1721.2	1778.3	1806.2	1802.5	1810.4	1826.9
Other direct personnel	325.9	368.0	380.7	377.9	352.9	355.4	359.7
Total direct personnel	1962.6	2089.2	2159.0	2184.1	2155.4	2165.8	2186.6
Isotopes	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Total indirect personnel	2218.4	2359.0	2435.7	2464.3	2432.5	2444.0	2467.1
Total Laboratory personnel	4217.0	4484.2	4630.0	4684.4	4623.9	4645.8	4689.7

Table A.5. Resources by program

($ in millions)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Assistant Secretary for Fossil Energy														
AA—Coal														
Total operating	5.88	6.92	6.16	7.35	6.60	7.39	6.70	7.09	6.70	6.70	6.70	6.70	6.70	6.70
Capital equipment	0		0.44		0.78		0.32		0.32		0.32		0.32	
Total program	5.88		6.61		7.38		7.02		7.02		7.02		7.02	
Technical personnel	21.6		23.5		24.4		20.7		20.7		20.7		20.7	
Other direct personnel	1.8		0.9		1.1		1.0		1.0		1.0		1.0	
Total direct personnel	23.4		24.4		25.5		21.7		21.7		21.7		21.7	
AC—Petroleum														
Total operating	0	0.04	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0.2		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0.2		0		0		0		0		0		0	
AZ—Innovative Clean Coal Technology														
Total operating	0.54	0.38	0.93	0.86	0.95	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Technical personnel	1.9		5.5		7.9		8.1		9.0		9.0		9.0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	1.9		5.5		7.9		8.1		9.0		9.0		9.0	
SA—Strategic Petroleum Reserve														
Total operating	0.26	0.20	0.26	0.28	0.28	0.35	0.25	0.25	0.20	0.20	0.20	0.20	0.20	0.20
Technical personnel	1.1		1.6		1.6		1.4		1.2		1.2		1.2	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	1.1		1.6		1.6		1.4		1.2		1.2		1.2	
Total Assistant Secretary for Fossil Energy														
Total operating	6.68	7.54	7.35	8.49	7.83	8.64	7.95	8.34	7.90	7.90	7.90	7.90	7.90	7.90
Capital equipment	0		0.44		0.78		0.32		0.32		0.32		0.32	
Total program	6.68		7.80		8.61		8.27		8.22		8.22		8.22	
Technical personnel	24.8		30.6		33.9		30.2		30.9		30.9		30.9	
Other direct personnel	1.8		0.9		1.1		1.0		1.0		1.0		1.0	
Total direct personnel	26.6		31.5		35.0		31.2		31.9		31.9		31.9	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Assistant Secretary for Nuclear Energy														
AF—Nuclear Energy Research and Development														
Total operating	31.59	29.70	30.51	29.51	30.71	30.62	32.63	32.52	31.07	30.90	31.12	31.42	30.21	30.51
Capital equipment	1.64		3.66		2.98		3.24		3.47		3.84		3.84	
Total program	33.23		34.17		33.69		35.87		34.54		34.95		34.05	
Technical personnel	137.7		143.7		146.4		150.2		152.0		152.4		148.3	
Other direct personnel	5.8		8.4		9.4		16.9		5.4		5.4		4.4	
Total direct personnel	143.5		152.1		155.8		167.1		157.4		157.8		152.7	
AH—Remedial Action and Waste Technology														
Total operating	8.51	6.84	2.71	2.71	1.59	1.59	1.27	1.27	1.05	1.05	0.85	0.85	0.85	0.85
Capital equipment	0.38		0.05		0.05		0.05		0.05		0.05		0.06	
Total program	8.89		2.76		1.64		1.32		1.10		0.90		0.91	
Technical personnel	31.8		32.8		24.8		21.7		14.6		14.6		14.6	
Other direct personnel	4.2		0.1		0.1		0		0		0		0	
Total direct personnel	36.0		32.9		24.9		21.7		14.6		14.6		14.6	
CD—Uranium Enrichment														
Total operating	0.42	0.42	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Technical personnel	1.7		1.0		1.0		1.0		1.0		1.0		1.0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	1.7		1.0		1.0		1.0		1.0		1.0		1.0	
Total Assistant Secretary for Nuclear Energy														
Total operating	40.53	36.95	33.53	32.52	32.60	32.51	34.20	34.09	32.42	32.25	32.27	32.57	31.36	31.66
Capital equipment	2.02		3.71		3.03		3.29		3.53		3.89		3.90	
Total	42.54		37.23		35.63		37.49		35.94		36.16		35.26	
Technical personnel	171.2		177.5		172.2		172.9		167.6		168.0		163.9	
Other direct personnel	10.0		8.5		9.5		16.9		5.4		5.4		4.4	
Total direct personnel	181.2		186.0		181.7		189.8		173.0		173.4		168.3	
Assistant Secretary for Conservation and Renewable Energy														
AK—Electric Energy Systems														
Total operating	3.12	4.06	4.89	4.95	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40
Capital equipment	0		0.04		0.05		0.05		0.05		0.05		0.05	
Total program	3.12		4.93		5.45		5.45		5.45		5.45		5.45	
Technical personnel	9.9		16.5		17.8		17.8		17.8		17.8		17.8	
Other direct personnel	1.5		0.4		0.4		0.4		0.4		0.4		0.4	
Total direct personnel	11.4		16.9		18.2		18.2		18.2		18.2		18.2	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
AL—Energy Storage Systems														
Total operating	0.87	0.55	1.10	1.10	1.20	1.20	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Technical personnel	2.0		2.0		2.0		2.0		2.0		2.0		2.0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	2.0		2.0		2.0		2.0		2.0		2.0		2.0	
AM—Geothermal Energy														
Total operating	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Technical personnel	0.7		0.5		0.5		0.5		0.5		0.5		0.5	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0.7		0.5		0.5		0.5		0.5		0.5		0.5	
AN—Energy Technology Center Program Direction														
Total operating	0.05	0	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Technical personnel	0		1.0		1.0		1.0		1.0		1.0		1.0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0		1.0		1.0		1.0		1.0		1.0		1.0	
CE—Hydropower														
Total operating	0.02	0.02	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0	
EB—Solar Energy														
Total operating	3.33	5.42	2.53	4.12	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01
Capital equipment	0.03		0.09		0.09		0.10		0.10		0.10		0.10	
Total program	3.36		2.62		4.10		4.12		4.12		4.12		4.12	
Technical personnel	10.7		9.7		10.6		10.6		10.6		10.6		10.6	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	10.7		9.7		10.6		10.6		10.6		10.6		10.6	
EC—Buildings and Community Systems														
Total operating	10.64	10.10	10.40	11.01	10.72	10.81	11.03	11.03	11.03	11.03	11.03	11.03	11.03	11.03
Capital equipment	0.15		0.62		0.61		0.60		0.60		0.60		0.60	
Total program	10.79		11.02		11.33		11.63		11.63		11.63		11.63	
Technical personnel	28.8		30.6		31.0		31.2		31.2		31.2		31.2	
Other direct personnel	2.6		0.7		0.7		0.7		0.7		0.7		0.7	
Total direct personnel	31.4		31.3		31.7		31.9		31.9		31.9		31.9	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
ED—Industrial Energy Conservation														
Total operating	2.19	1.65	2.45	2.35	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
Capital equipment	0		0.07		0.04		0		0		0		0	
Total program	2.19		2.52		2.49		2.45		2.45		2.45		2.45	
Technical personnel	8.4		11.4		12.8		12.8		12.8		12.8		12.8	
Other direct personnel	0.4		0.6		0.6		0.6		0.6		0.6		0.6	
Total direct personnel	8.8		12.0		13.4		13.4		13.4		13.4		13.4	
EE—Transportation														
Total operating	17.27	14.65	19.76	18.59	19.96	19.94	20.16	19.96	20.16	20.16	20.16	20.16	20.16	20.16
Capital equipment	0.25		0.50		1.00		1.00		1.00		1.00		1.00	
Total program	17.52		20.26		20.96		21.16		21.16		21.16		21.16	
Technical personnel	37.1		46.7		47.2		47.2		47.2		47.2		47.3	
Other direct personnel	3.9		0.4		0.4		0.4		0.4		0.4		0.4	
Total direct personnel	41.0		47.1		47.6		47.6		47.6		47.6		47.7	
EF—State/Local Programs														
Total operating	0.42	0.15	0.30	0.48	0.50	0.50	0.55	0.50	0.50	0.50	0.50	0.50	0.50	0.55
Technical personnel	0.2		1.8		1.8		1.8		1.8		1.8		1.8	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0.2		1.8		1.8		1.8		1.8		1.8		1.8	
EG—Multi-Sector														
Total operating	5.90	5.92	6.65	6.45	6.85	6.85	7.76	6.86	7.76	6.86	7.76	6.86	7.76	6.86
Capital equipment	0.30		0.77		0.70		0.50		0.50		0.50		0.50	
Total program	6.20		7.41		7.55		8.26		8.26		8.26		8.26	
Technical personnel	22.3		24.4		24.4		24.4		24.4		24.4		24.4	
Other direct personnel	0.2		0		0		0		0		0		0	
Total direct personnel	22.5		24.4		24.4		24.4		24.4		24.4		24.4	
Total Assistant Secretary for Conservation and Renewable Energy														
Total operating	43.87	42.59	48.31	49.29	51.32	51.39	52.83	51.68	52.79	51.89	52.79	51.89	52.79	51.93
Capital equipment	0.73		2.09		2.48		2.25		2.25		2.25		2.25	
Total	44.60		50.39		53.80		55.08		55.03		55.03		55.03	
Technical personnel	120.1		144.6		149.1		149.3		149.3		149.3		149.4	
Other direct personnel	8.6		2.1		2.1		2.1		2.1		2.1		2.1	
Total direct personnel	128.7		146.7		151.2		151.4		151.4		151.4		151.5	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Assistant Secretary for International Affairs and Energy Emergencies														
NA—International Affairs														
Total operating	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0	
Total Assistant Secretary for International Affairs and Energy Emergencies														
Total operating	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0	
Office of Energy Research														
AT—Magnetic Fusion														
Total operating	39.44	39.16	34.91	36.02	37.57	37.67	38.77	38.77	38.77	38.77	38.77	38.77	38.77	38.77
Capital equipment	7.51		6.40		12.71		12.69		12.66		12.64		12.62	
Construction	7.20		6.60		0		0		0		0		0	
Total program	54.15		47.91		50.29		51.46		51.43		51.41		51.39	
Proposed construction	0		0		9.50		10.50		10.50		10.50		10.50	
Technical personnel	120.3		113.5		113.5		113.5		113.5		113.5		113.5	
Other direct personnel	87.6		67.5		67.5		67.5		67.5		67.5		67.5	
Total direct personnel	207.9		181.0		181.0		181.0		181.0		181.0		181.0	
HA—Environmental Research and Development														
Total operating	23.21	23.53	24.70	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Capital equipment	1.20		1.17		1.50		2.00		2.00		2.00		2.00	
Total program	24.41		25.88		26.50		27.00		27.00		27.00		27.00	
Proposed construction	0		0		0		1.50		11.90		3.70		0	
Technical personnel	125.0		127.0		127.0		127.0		127.0		127.0		127.0	
Other direct personnel	6.7		7.0		7.0		7.0		7.0		7.0		7.0	
Total direct personnel	131.7		134.0		134.0		134.0		134.0		134.0		134.0	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
KA—High Energy Physics														
Total operating	0.48	0.48	0.68	0.68	0.78	0.80	0.66	0.65	0.66	0.65	0.66	0.65	0.66	0.65
Capital equipment	0		0		0.02		0.02		0.02		0.02		0.02	
Total program	0.48		0.68		0.80		0.67		0.67		0.67		0.67	
Technical personnel	2.0		4.0		4.2		3.2		3.2		3.2		3.2	
Other direct personnel	0.8		0.4		0.5		0.5		0.5		0.5		0.5	
Total direct personnel	2.8		4.4		4.7		3.7		3.7		3.7		3.7	
KB—Nuclear Physics														
Total operating	13.62	13.68	13.80	13.80	14.46	14.46	15.17	15.17	15.21	15.21	15.26	15.26	15.26	15.26
Capital equipment	0.96		1.03		1.50		1.20		1.20		1.20		1.20	
Total program	14.58		14.83		15.97		16.37		16.41		16.46		16.46	
Proposed construction	0		0		0.55		0		0		0		0	
Technical personnel	70.6		69.1		68.7		68.7		68.9		69.2		69.2	
Other direct personnel	17.2		16.3		16.1		16.1		16.0		16.0		16.0	
Total direct personnel	87.8		85.4		84.8		84.8		84.9		85.2		85.2	
KC—Basic Energy Sciences														
Total operating	65.69	71.30	72.97	72.97	80.57	80.57	76.97	76.97	76.65	76.65	77.61	77.61	77.68	77.68
Capital equipment	5.71		4.51		8.74		9.04		8.23		8.24		8.25	
Total program	71.40		77.48		89.31		86.01		84.88		85.85		85.93	
Proposed construction	0		0.72		4.10		19.20		15.70		18.70		35.50	
Technical personnel	325.1		338.7		340.9		331.4		329.5		329.9		330.4	
Other direct personnel	98.7		112.8		112.3		100.8		100.8		100.8		100.8	
Total direct personnel	423.8		451.5		453.2		432.2		430.3		430.7		431.2	
KD—Energy Research Analyses														
Total operating	1.08	1.21	1.08	1.08	0.79	0.79	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Technical personnel	0.7		4.5		2.3		2.3		2.3		2.3		2.3	
Other direct personnel	1.6		0.1		0		0		0		0		0	
Total direct personnel	2.3		4.6		2.3		2.3		2.3		2.3		2.3	
KE—University Research Support														
Total operating	0.44	0.41	1.20	1.20	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Technical personnel	0.3		1.4		1.5		1.5		1.5		1.5		1.5	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0.3		1.4		1.5		1.5		1.5		1.5		1.5	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
KG—Multiprogram Energy Laboratories Facilities Support														
Total operating	14.30	14.30	11.37	11.37	12.11	12.11	13.12	13.12	14.56	14.56	15.45	15.45	18.33	18.33
Capital equipment	0.40		0.40		0.40		0.40		0.40		0.40		0.40	
Construction	21.10		14.70		13.30		5.45		0		0		0	
Total program	35.80		26.47		25.81		18.97		14.96		15.85		18.73	
Proposed construction	0		7.50		12.00		21.10		25.70		34.10		32.80	
Technical personnel	61.1		55.4		54.4		65.0		73.0		77.0		92.0	
Other direct personnel	0		13.9		13.6		15.7		17.5		18.5		22.0	
Total direct personnel	61.1		69.3		68.0		80.7		90.5		95.5		114.0	
Office of Energy Research														
Total operating	158.25	164.06	160.70	162.11	172.58	172.70	171.77	171.76	172.93	172.92	174.82	174.82	177.78	177.78
Capital equipment	15.78		13.51		24.88		25.34		24.50		24.49		24.48	
Construction	28.30		21.30		13.30		5.45		0		0		0	
Total	202.33		195.51		210.76		202.56		197.43		199.31		202.26	
Proposed construction	0		8.22		26.14		52.30		63.80		67.00		78.80	
Technical personnel	705.1		713.6		712.5		712.6		718.9		723.6		739.1	
Other direct personnel	212.6		218.0		217.0		207.6		209.3		210.3		213.8	
Total direct personnel	917.7		931.6		929.5		920.2		928.2		933.9		952.9	
Assistant Secretary for Defense Programs														
GB—Weapons Activities														
Total operating	1.45	1.35	1.70	1.70	1.62	1.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Capital equipment	0		0.02		0.02		0.02		0.02		0.02		0.02	
Total program	1.45		1.72		1.64		0.64		0.64		0.64		0.64	
Technical personnel	1.7		2.8		2.8		1.8		1.8		1.8		1.8	
Other direct personnel	0.7		3.5		2.7		2.7		2.7		2.7		2.7	
Total direct personnel	2.4		6.3		5.5		4.5		4.5		4.5		4.5	
GC—Verification and Control Technology														
Total operating	0	0.17	0.25	0.25	0.25	0.25	0.15	0.15	0	0	0	0	0	0
Technical personnel	1.7		2.0		2.0		1.2		0		0		0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	1.7		2.0		2.0		1.2		0		0		0	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
GD—Nuclear Safeguards and Security														
Total operating	0.56	0.56	0.44	0.44	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
Capital equipment	0.05		0.05		0.18		0.08		0.08		0.08		0.08	
Total program	0.61		0.49		0.63		0.53		0.53		0.53		0.53	
Technical personnel	3.5		3.5		3.5		3.5		3.4		3.3		3.2	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	3.5		3.5		3.5		3.5		3.4		3.3		3.2	
GE—Materials Production														
Total operating	7.30	7.08	4.08	4.12	5.00	5.01	6.94	6.44	6.92	6.42	6.92	6.42	6.92	6.42
Capital equipment	0.20		0.20		0.21		0.21		0.15		0.15		0.15	
Total program	7.50		4.27		5.20		7.15		7.07		7.07		7.07	
Technical personnel	45.0		28.3		33.1		43.0		41.0		41.0		41.0	
Other direct personnel	5.2		2.5		2.0		2.0		1.0		1.0		1.0	
Total direct personnel	50.2		30.8		35.1		45.0		42.0		42.0		42.0	
GF—Defense Waste and Environmental Restoration														
Total operating	22.12	21.67	28.38	28.37	73.51	73.51	86.16	86.16	120.33	120.33	119.19	119.19	95.12	95.12
Capital equipment	1.20		1.23		3.51		2.63		2.65		2.68		2.75	
Construction	4.40		0		0		0		0		0		0	
Total program	27.73		29.61		77.02		88.79		122.98		121.87		97.87	
Proposed construction	0		2.50		3.15		4.24		30.00		25.00		50.00	
Technical personnel	77.1		93.0		127.6		141.2		139.8		142.3		144.8	
Other direct personnel	1.8		35.1		39.7		44.3		35.4		35.6		36.0	
Total direct personnel	78.9		128.1		167.3		185.5		175.2		177.9		180.8	
Total Assistant Secretary for Defense Programs														
Total operating	31.42	30.83	34.84	34.88	80.84	80.85	94.33	93.83	128.33	127.83	127.19	126.69	103.13	102.62
Capital equipment	1.45		1.50		3.91		2.94		2.90		2.93		2.99	
Construction	4.40		0		0		0		0		0		0	
Total	37.28		36.34		84.75		97.27		131.23		130.11		106.12	
Proposed construction	0		2.50		3.15		4.24		30.00		25.00		50.00	
Technical personnel	129.0		129.6		169.0		190.7		186.0		188.4		190.8	
Other direct personnel	7.7		41.1		44.4		49.0		39.1		39.3		39.7	
Total direct personnel	136.7		170.7		213.4		239.7		225.1		227.7		230.5	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Assistant Secretary for Environment, Safety, and Health														
HA—Environment, Safety, and Health														
Total operating	8.10	8.84	6.00	6.74	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Capital equipment	0.13		0.05		0.07		0.05		0.05		0.05		0.05	
Total program	8.23		6.05		6.06		6.05		6.05		6.05		6.05	
Technical personnel	36.5		27.0		22.0		22.0		22.0		22.0		22.0	
Other direct personnel	4.2		3.0		3.0		3.0		3.0		3.0		3.0	
Total direct personnel	40.7		30.0		25.0		25.0		25.0		25.0		25.0	
Total Assistant Secretary for Environment, Safety, and Health														
Total operating	8.10	8.84	6.00	6.74	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Capital equipment	0.13		0.05		0.07		0.05		0.05		0.05		0.05	
Total	8.23		6.05		6.06		6.05		6.05		6.05		6.05	
Technical personnel	36.5		27.0		22.0		22.0		22.0		22.0		22.0	
Other direct personnel	4.2		3.0		3.0		3.0		3.0		3.0		3.0	
Total direct personnel	40.7		30.0		25.0		25.0		25.0		25.0		25.0	
Federal Energy Regulatory Commission														
VR—Federal Energy Regulatory Commission														
Total operating	0.09	1.43	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Technical personnel	6.7		1.5		1.5		1.5		1.5		1.5		1.5	
Other direct personnel	0.1		0		0		0		0		0		0	
Total direct personnel	6.8		1.5		1.5		1.5		1.5		1.5		1.5	
Total Federal Energy Regulatory Commission														
Total operating	0.09	1.43	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Technical personnel	6.7		1.5		1.5		1.5		1.5		1.5		1.5	
Other direct personnel	0.1		0		0		0		0		0		0	
Total direct personnel	6.8		1.5		1.5		1.5		1.5		1.5		1.5	
Economic Regulatory Administration														
UE—Natural Gas and Electricity Operations														
Total operating	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Total Economic Regulatory Administration														
Total operating	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0	
Energy Information Administration														
TA—Energy Information Administration System														
Total operating	1.07	1.68	1.50	1.75	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Technical personnel	2.6		2.6		2.6		2.6		2.6		2.6		2.6	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	2.6		2.6		2.6		2.6		2.6		2.6		2.6	
Total Energy Information Administration														
Total operating	1.07	1.68	1.50	1.75	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Technical personnel	2.6		2.6		2.6		2.6		2.6		2.6		2.6	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	2.6		2.6		2.6		2.6		2.6		2.6		2.6	
Office of Policy, Planning, and Analysis														
PE—Policy, Planning, and Analysis														
Total operating	0.22	0.23	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Technical personnel	0.4		1.1		1.0		1.0		1.0		1.0		1.0	
Other direct personnel	0.1		0		0		0		0		0		0	
Total direct personnel	0.5		1.1		1.0		1.0		1.0		1.0		1.0	
Total Office of Policy, Planning, and Analysis														
Total operating	0.22	0.23	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Technical personnel	0.4		1.1		1.0		1.0		1.0		1.0		1.0	
Other direct personnel	0.1		0		0		0		0		0		0	
Total direct personnel	0.5		1.1		1.0		1.0		1.0		1.0		1.0	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Office of Civilian Radioactive Waste Management														
DB—Nuclear Waste Fund														
Total operating	10.94	9.51	10.94	10.94	10.92	10.92	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02
Capital equipment	0.01		0.06		0.02		0.02		0.02		0.02		0.02	
Total program	10.95		11.00		10.93		11.03		11.03		11.03		11.03	
Technical personnel	29.0		39.5		38.1		39.1		39.1		39.1		39.1	
Other direct personnel	7.5		11.0		11.7		12.0		12.0		12.0		12.0	
Total direct personnel	36.5		50.5		49.8		51.1		51.1		51.1		51.1	
DC—Civilian Radioactive Waste Research and Development														
Total operating	0.15	0.13	0	0.01	0	0	0	0	0	0	0	0	0	0
Technical personnel	0.3		0.1		0		0		0		0		0	
Other direct personnel	0.9		0		0		0		0		0		0	
Total direct personnel	1.2		0.1		0		0		0		0		0	
Total Office of Civilian Radioactive Waste Management														
Total operating	11.09	9.64	10.94	10.95	10.92	10.92	11.02	11.02	11.02	11.02	11.02	11.02	11.02	11.02
Capital equipment	0.01		0.06		0.02		0.02		0.02		0.02		0.02	
Total	11.10		11.00		10.93		11.03		11.03		11.03		11.03	
Technical personnel	29.3		39.6		38.1		39.1		39.1		39.1		39.1	
Other direct personnel	8.4		11.0		11.7		12.0		12.0		12.0		12.0	
Total direct personnel	37.7		50.6		49.8		51.1		51.1		51.1		51.1	
Assistant Secretary for Management and Administration														
WB—In-House Energy Management														
Total operating	0.26	0.18	0.08	0.16	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Technical personnel	0		0		0		0		0		0		0	
Other direct personnel	0.3		0.3		0.3		0.3		0.3		0.3		0.3	
Total direct personnel	0.3		0.3		0.3		0.3		0.3		0.3		0.3	
WG—Strategic Facilities Utilization Program														
Total operating	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Technical personnel	0		0		0		0		0		0		0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0		0		0		0		0		0		0	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
WM—Services														
Total operating	0.09	0.06	0.04	0.07	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Technical personnel	0.2		0.3		0.3		0.3		0.3		0.3		0.3	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	0.2		0.3		0.3		0.3		0.3		0.3		0.3	
Total Assistant Secretary for Management and Administration														
Total operating	0.35	0.24	0.12	0.23	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Technical personnel	0.2		0.3		0.3		0.3		0.3		0.3		0.3	
Other direct personnel	0.3		0.3		0.3		0.3		0.3		0.3		0.3	
Total direct personnel	0.5		0.6		0.6		0.6		0.6		0.6		0.6	
Subtotal DOE Programs														
Total operating	301.66	304.07	303.83	307.50	364.50	365.42	380.52	379.15	413.80	412.23	414.41	413.30	392.40	391.34
Capital equipment	20.11		21.36		35.16		34.20		33.55		33.93		34.00	
Construction	32.70		21.30		13.30		5.45		0		0		0	
Total	354.48		346.49		412.96		420.17		447.36		448.34		426.40	
Proposed construction	0		10.72		29.30		56.54		93.80		92.00		128.80	
Technical personnel	1225.9		1268.0		1302.2		1322.2		1319.2		1326.7		1340.6	
Other direct personnel	253.8		284.9		289.1		291.9		272.2		273.4		276.3	
Total direct personnel	1479.7		1552.9		1591.3		1614.1		1591.4		1600.1		1616.9	
DOE Contractors and Operations Office														
Total operating	18.15	15.84	15.72	16.29	16.35	16.35	16.19	15.75	17.79	17.79	17.89	17.89	16.49	16.49
Capital equipment	0		1.36		0		0		0		0		0	
Total program	18.15		17.08		16.35		16.19		17.79		17.89		16.49	
Technical personnel	83.7		80.6		74.7		74.7		74.7		74.7		74.7	
Other direct personnel	15.3		15.3		16.8		15.8		15.8		15.8		15.8	
Total direct personnel	99.0		95.9		91.5		90.5		90.5		90.5		90.5	
Total DOE Programs														
Total operating	319.81	319.91	319.56	323.79	380.85	381.77	396.71	394.90	431.59	430.02	432.30	431.19	408.88	407.82
Capital equipment	20.11		22.72		35.16		34.20		33.55		33.93		34.00	
Construction	32.70		21.30		13.30		5.45		0		0		0	
Total program	372.63		363.57		429.31		436.36		465.15		466.23		442.89	
Proposed construction	0		10.72		29.30		56.54		93.80		92.00		128.80	
Technical personnel	1309.6		1348.6		1376.9		1396.9		1393.9		1401.4		1415.3	
Other direct personnel	269.1		300.2		305.9		307.7		288.0		289.2		292.1	
Total direct personnel	1578.7		1648.8		1682.8		1704.6		1681.9		1690.6		1707.4	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Work for Others														
Department of Defense														
Total operating[b]	14.73	14.73	30.92	30.92	37.56	37.56	39.64	39.64	40.00	40.00	40.00	40.00	40.30	40.30
Capital equipment	0.38		0.15		0.15		0.15		0.15		0.15		0.15	
Total program	15.11		31.07		37.71		39.79		40.15		40.15		40.45	
Technical personnel	72.8		113.9		136.6		146.8		148.0		146.3		145.6	
Other direct personnel	8.7		10.1		17.3		18.3		17.9		18.8		19.8	
Total direct personnel	81.5		124.0		153.9		165.1		165.9		165.1		165.4	
Department of Defense Data Systems														
Total operating[b]	34.80	21.02	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Technical personnel	35.1		35.0		35.0		35.0		35.0		35.0		35.0	
Other direct personnel	14.0		10.0		10.0		10.0		10.0		10.0		10.0	
Total direct personnel	49.1		45.0		45.0		45.0		45.0		45.0		45.0	
Other Agencies Data Systems														
Total operating[b]	0.89	0.88	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Technical personnel	2.1		2.0		2.0		2.0		2.0		2.0		2.0	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	2.1		2.0		2.0		2.0		2.0		2.0		2.0	
Hazardous Waste Research and Development														
Total operating[b]	8.79	6.18	6.50	6.50	7.50	7.50	8.00	8.00	8.50	8.50	9.00	9.00	9.50	9.50
Capital equipment	0.10		0.06		0.05		0.05		0.05		0.05		0.05	
Total program	8.89		6.56		7.55		8.05		8.55		9.05		9.55	
Technical personnel	28.5		30.0		38.0		38.0		40.0		42.0		45.0	
Other direct personnel	3.4		5.4		6.2		6.6		7.1		7.5		7.9	
Total direct personnel	31.9		35.4		44.2		44.6		47.1		49.5		52.9	
Department of Transportation														
Total operating[b]	0.40	0.42	0.51	0.51	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Technical personnel	1.4		2.2		2.2		2.2		2.2		2.2		2.2	
Other direct personnel	0		0		0		0		0		0		0	
Total direct personnel	1.4		2.2		2.2		2.2		2.2		2.2		2.2	
Federal Emergency Management Agency														
Total operating[b]	1.67	2.16	2.00	2.26	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
Technical personnel	8.0		8.0		8.0		8.0		8.0		8.0		8.0	
Other direct personnel	2.4		2.4		2.4		2.4		2.4		2.4		2.4	
Total direct personnel	10.4		10.4		10.4		10.4		10.4		10.4		10.4	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Nuclear Regulatory Commission														
Total operating[b]	14.64	14.44	14.63	14.60	16.26	16.26	16.26	16.26	16.28	16.28	16.32	16.32	16.38	16.38
Capital equipment	0.15		0.04		0.02		0.02		0.02		0.02		0.02	
Total program	14.80		14.67		16.28		16.28		16.30		16.34		16.40	
Technical personnel	65.0		60.0		60.6		60.6		60.6		60.7		61.0	
Other direct personnel	9.3		10.6		12.5		12.5		12.5		12.5		12.5	
Total direct personnel	74.3		70.6		73.1		73.1		73.1		73.2		73.5	
Department of Health and Human Services														
Total operating[b]	5.28	5.28	5.30	5.30	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50
Technical personnel	34.1		34.0		34.0		34.0		34.0		34.0		34.0	
Other direct personnel	0.3		0.5		0.5		0.5		0.5		0.5		0.5	
Total direct personnel	34.4		34.5		34.5		34.5		34.5		34.5		34.5	
Environmental Protection Agency														
Total operating[b]	4.74	4.74	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Capital equipment	0.06		0.05		0.05		0.05		0.05		0.05		0.05	
Total program	4.80		5.05		5.05		5.05		5.05		5.05		5.05	
Technical personnel	21.5		22.0		22.0		22.0		22.0		22.0		22.0	
Other direct personnel	0.3		1.0		1.0		1.0		1.0		1.0		1.0	
Total direct personnel	21.8		23.0		23.0		23.0		23.0		23.0		23.0	
National Science Foundation														
Total operating[b]	1.16	1.16	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Technical personnel	5.8		7.0		7.0		7.0		7.0		7.0		7.0	
Other direct personnel	0		0.5		0.5		0.5		0.5		0.5		0.5	
Total direct personnel	5.8		7.5		7.5		7.5		7.5		7.5		7.5	
Tennessee Valley Authority														
Total operating[b]	0.94	0.94	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Technical personnel	3.6		4.0		4.0		4.0		4.0		4.0		4.0	
Other direct personnel	1.0		1.0		1.0		1.0		1.0		1.0		1.0	
Total direct personnel	4.6		5.0		5.0		5.0		5.0		5.0		5.0	

Table A.5 (continued)

	FY 1988[a]		FY 1989[a]		FY 1990[a]		FY 1991[a]		FY 1992		FY 1993		FY 1994	
	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO	BA	BO
Other Federal Agencies														
Total operating[b]	9.15	8.31	14.64	14.67	18.91	18.95	16.63	16.67	6.28	6.31	6.28	6.31	6.28	6.31
Capital equipment	0		1.02		0.84		0.10		0		0		0	
Total program	9.15		15.66		19.76		16.73		6.28		6.28		6.28	
Technical personnel	26.0		29.2		28.3		26.3		22.4		22.4		22.4	
Other direct personnel	16.5		25.0		22.1		16.1		10.7		10.7		10.7	
Total direct personnel	42.5		54.2		50.4		42.4		33.1		33.1		33.1	
Electric Power Research Institute														
Total operating[b]	4.64	4.64	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Technical personnel	14.6		15.0		15.0		15.0		15.0		15.0		15.0	
Other direct personnel	0.6		0.5		0.5		0.5		0.5		0.5		0.5	
Total direct personnel	15.2		15.5		15.5		15.5		15.5		15.5		15.5	
Other Nonfederal Agencies														
Total operating[b]	1.79	1.94	2.13	2.13	1.83	1.83	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
Technical personnel	8.6		10.3		8.7		8.4		8.4		8.4		8.4	
Other direct personnel	0.3		0.8		0.8		0.8		0.8		0.8		0.8	
Total direct personnel	8.9		11.1		9.5		9.2		9.2		9.2		9.2	
Total Work for Others														
Total operating[b]	103.64	86.85	105.01	105.27	118.81	118.84	119.08	119.12	109.61	109.64	110.15	110.18	111.01	111.04
Capital equipment	0.69		1.32		1.11		0.37		0.27		0.27		0.27	
Total	104.33		106.33		119.92		119.45		109.88		110.42		111.28	
Technical personnel	327.1		372.6		401.4		409.3		408.6		409.0		411.6	
Other direct personnel	56.8		67.8		74.8		70.2		64.9		66.2		67.6	
Total direct personnel	383.9		440.4		476.2		479.5		473.5		475.2		479.2	
Total Program Resources														
Total operating	423.45	406.75	424.56	429.07	499.66	500.61	515.79	514.02	541.20	539.66	542.45	541.37	519.89	518.87
Capital equipment	20.81		24.04		36.27		34.57		33.83		34.21		34.27	
Construction	32.70		21.30		13.30		5.45		0		0		0	
Total	476.96		469.90		549.23		555.81		575.02		576.65		554.17	
Proposed construction	0		10.72		29.30		56.54		93.80		92.00		128.80	
Technical personnel	1636.7		1721.2		1778.3		1806.2		1802.5		1810.4		1826.9	
Other direct personnel	325.9		368.0		380.7		377.9		352.9		355.4		359.7	
Total direct personnel	1962.6		2089.2		2159.0		2184.1		2155.4		2165.8		2186.6	

[a]Escalation factors from FY 1988 to FY 1989 and from FY 1989 to FY 1990 are both 4.5%. Figures for FY 1991 through FY 1994 are in constant FY 1990 dollars.

[b]Includes subcontracts and funds for acquired support from other sites.

Table A.6. Major construction projects

($ in thousands)

Construction projects	Type of cons.	B&R code	Project year	Prior years	Fiscal year 1988	1989	1990	1991	1992	1993	1994	Total estimated cost
Nonradiological wastewater treatment plant	LI	KG02	1983	9,900	6,987							16,887
ARIM-HFIR	ARIM	KC03	1987	430								430
ARIM-beam lines for atomic physics, HHIRF	ARIM	KC03	1987	300								300
LLW system upgrade, Bethel Valley	LI	KG02	1988		4,800	11,700	13,300	5,200				35,000
Total budgeted and funded programmatic					11,787	11,700	13,300	5,200	0	0	0	52,617
Piping systems restoration (ORNL at Y-12)	LI	KG01	1987	725	2,475	600						3,800
Upgrade steam distribution system	LI	KG01	1987	1,328	5,472							6,800
Upgrade fire protection (ORNL at Y-12)	LI	KG01	1988		770	980						1,750
Building piping systems upgrade (ORNL at Y-12)	LI	KG01	1988		520	1,330						1,850
Total budgeted and funded MGPF					9,237	2,910	0	0	0	0	0	14,200
Total funded					21,024	14,610	13,300	5,200	0	0	0	66,817
AIM-HFIR	AIM	KC03	1989			720						720
AIM-HHIRF beam TRNS (upgrade)	AIM	KB02	1990				545					545
Safety improvements, HFIR	LI	KC03	1990				1,300	2,800	2,400	1,000		7,500
AIM-Multicharged Ion Research Facility	AIM	KC03	1990				480					480
Molecular Genetics Laboratory	LI	HA02	1991					1,100	9,000			10,100
Upgrade air supply, Part I	LI	HA02	1991					400	2,600			3,000
Advanced Neutron Source (ANS)	LI	KC02	1991					9,500	10,000	14,600	39,512	412,000
AIM-electron target, HHIRF EN Tandem	AIM	KC03	1991					720				720
Heavy Ion Storage Ring for Atomic Physics (HISTRAP)	LI	KC03	1991					5,000	6,000	4,000	1,900	16,900
AIM-upgrade ECR source	AIM	KC03	1991					510				510
Isotopes area LLW CAT system upgrade	LI	KG02	1991					5,800	10,900	7,700	2,800	27,200

Table A.6 (continued)

Construction projects	Type of cons.	B&R code	Project year	Prior years	Fiscal year 1988	1989	1990	1991	1992	1993	1994	Total estimated cost
Class II disposal facilities	LI	GF01	1992						10,000	10,000	5,000	25,000
Waste Handling and packaging plant	LI	GF11	1992						20,000	25,000	50,000	130,000
Upgrade air supply, Part II	LI	HA02	1992						300	3,700		4,000
Melton Valley LLW CAT system upgrade	LI	KG02	1992						3,000	10,000	7,000	20,000
Decontamination facility	LI	KG02	1994								3,000	20,000
Total proposed programmatic						720	2,325	25,830	74,200	76,000	109,212	678,675
Roads and parking rehabilitation	LI	KG01	1989			1,650	870					2,520
Electrical systems upgrade	LI	KG01	1990				855	1,445				2,300
Fire protection upgrade	LI	KG01	1990				1,340	1,360				2,700
Measurement and Control Support Facility	LI	KG01	1990				1,100	3,100	230			4,430
Central Research and Support Building	LI	KG01	1991					1,095	5,355	650		7,100
Replace obsolete maintenance and laundry facilities	LI	KG01	1992						1,000	4,000	1,800	6,800
Upgrade steam distribution, West End	LI	KG01	1992						1,415	2,850	1,835	6,100
Asbestos abatement and research facility restoration	LI	KG01	1993							1,000	3,165	10,500
ALARA Program Support Facility	LI	KG01	1994								1,200	8,400
Electrical systems upgrade (ORNL at Y-12)	LI	KG01	1994								1,000	4,200
Building cooling system upgrade	LI	KG01	199X									7,000
Met. Exam. Hot Cell systems upgrade	LI	KG01	199X									12,000
Safeguards and security building	LI	KG01	199X									7,500
Steam Plant I	LI	KG01	199X									8,000
Total proposed MGPF[a]						1,650	4,165	7,000	8,000	8,500	9,000	89,550
Total proposed						2,370	6,490	32,830	82,200	84,500	118,212	768,225
Total funded and proposed					21,024	16,980	19,790	38,030	82,200	84,500	118,212	835,042

[a]The MGPF project requirements for the Laboratory are currently under review. Particularly in the out years, this listing will represent only a subset of the actual requirements.

Table A.7. Subcontracting and procurement by fiscal year

($ in millions)

	1987	1988	1989	1990
Subcontracts and procurement with universities	18.7	19.9	18.6	18.5
All other subcontracts and procurements	115.4	110.2	108.4	103.9
Transfer to other DOE facilities	3.3	4.1	3.4	3.3
Total	137.4	134.2	130.4	125.7

Acronyms

ACP	Advanced Computer Project
ACTO	Advanced Control Test Operation
ACTP	Advanced Control Technology Program
ADP	Automated Data Processing
ADCOH	Appalachian Ultradeep Core Hole
AEOD	Analysis and Evaluation of Operational Data
AFWAL	Air Force Wright Aeronautical Laboratory
AGMEF	Ana G. Méndez Educational Foundation
AGS	Alternating Gradient Synchrotron
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
APSC	Advanced Processing Science Center
AR&TD	Advanced Research and Technology Development
ARIES	Advanced Reactor Innovation and Evaluation Study
ARIM	Accelerator and Reactor Improvement and Modification
ASCRE	Assistant Secretary for Conservation and Renewable Energy

ASDP	Assistant Secretary for Defense Programs
ASESH	Assistant Secretary for Environment, Safety, and Health
ASFE	Assistant Secretary for Fossil Energy
ASM	advanced servomanipulator
ASNE	Assistant Secretary for Nuclear Energy
ATD	Applied Technology Division
ATF	Advanced Toroidal Facility
ATSDR	Agency for Toxic Solutions and Disease Registry
ATSER	Agency for Toxic Substances and Emergency Response
AVLIS	Atomic Vapor Laser Isotope Separation
BA	budget authorization
BES	Basic Energy Sciences
BNL	Brookhaven National Laboratory
BO	budget outlay or budget obligation
BRF	Bioprocessing Research Facility
BRS	broad-range magnetic spectrograph
BSR	Bulk Shielding Reactor
BTESM	Building Thermal Envelope Systems and Materials
CBCF	carbon-bonded carbon fiber
CCP	Clean Coal Program
CDIAC	Carbon Dioxide Information Analysis Center
CDIARP	Carbon Dioxide Information Analyses and Research Program
CDRD	Carbon Dioxide Research Division
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act

CERN	Conseil Européen pour Recherche Nucléaire
CESAR	Center for Engineering Systems Advanced Research
CEUSP	Consolidated Edison Uranium Solidification Program
CFC	chlorinated fluorocarbon
CFRP	Consolidated Fuel Reprocessing Program
CFTL	component flow test loop
CH	contact handled
CIT	Compact Ignition Tokamak
COSPLUM	Crystalline Overthrust Structures on the Platform Localizing Unconventional Methane
CRE	Conservation and Renewable Energy
CURE	chemical unit risk analysis
CVI	chemical vapor infiltration
CWDF	Central Waste Disposal Facility
DACE	design and computational experiments
DARPA	Defense Advanced Research Project Agency
D&T	Development and Technology
DHHS	Department of Health and Human Services
DIII-D	Doublet III-D tokamak
DNA	deoxyribonucleic acid or Defense Nuclear Agency
DOD	Department of Defense
DOE	Department of Energy
DOE-SPC	Department of Energy–Superconductivity Pilot Centers
DOI	Department of Interior

DOT	Department of Transportation or Department of Treasury
DP	Defense Program
DSRD	Data Systems Research and Development
D-T	deuterium-tritium
DTP	Defense Technology Program
DTRC	David W. Taylor Naval Ship Research and Development Center
ECH	electron cyclotron heating
ECR	electron cyclotron resonance
ECUT	Energy Conversion and Utilization Technologies
EGF	epidermal growth factor
EH&S	environmental, health, and safety
EIA	Energy Information Administration
EIS	Environmental Impact Statements
EPA	Environmental Protection Agency
EPRI	Electric Power Reasearch Institute
ESC	Ecological Study Center
ESD	Environmental Sciences Division
ETP	Emergency Technology Program
FDA	Food and Drug Administration
FEDC	Fusion Energy Design Center
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FHWA	Federal Highway Administration
FIS	fiber-optic-based fluoroimmunosensor

FORSCOM	U.S. Forces Command
FTE	full-time equivalent or full-time
GLCA/ACM	Great Lakes Colleges Association/Associated Colleges of the Midwest
GPA	grade point average
GPE	general purpose equipment
GPP	general plant project
GRI	Gas Research Institute
HASRD	Health and Safety Research Division
HAZWDDD	Hazardous Waste Disposal Development and Demonstration
HAZWRAP	Hazardous Waste Remedial Action Program
HBCU	historically black colleges and universities
HE	high explosives
HERMIES	Hostile Environment Robotic Machine Intelligence Experiment Series
HFIR	High-Flux Isotope Reactor
HHIRF	Holifield Heavy Ion Research Facility
HIFI	HFIR Irradiation Facility Improvement
HILI	Heavy Ion Light Ion
HISTRAP	Heavy Ion Storage Ring for Atomic Physics
HWL	high-level waste
HPRR	Health Physics Research Reactor
HQ	headquarters
HTGR	high-temperature gas-cooled reactor
HTML	High Temperature Materials Laboratory
HWM	Hazardous Waste Management

HWR	heavy water reactor
HWTP	Hazardous Waste Technology Program
IAEA	International Atomic Energy Agency
ICE	independent cost-estimating
ICP	Institute for Computational Physics
ICRF	ion cyclotron range-of-frequency
ICRP	International Commission on Radiological Protection
IET	Integrated Equipment Test
IFSMTF	International Fusion Superconducting Magnet Test Facility
INEL	Idaho National Engineering Laboratory
IRI	Industrial Research Institute
ITER	International Thermonuclear Experimental Reactor
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
LGP	Laboratory Graduate Participation
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
LLWDDD	Low-Level Waste Disposal Development and Demonstration
LMF	Liquid Metal Fast Breeder Reactor
LMR	liquid metal reactor

LTNIF	Low-Temperature Neutron Irradiation Facility
LWR	light-water reactor
MEI	Minority Educational Institution
MEOR	microbial-enhanced oil recovery
METC	Morgantown Energy Technology Center
MGPF	Multiprogram General-Purpose Facilities
MHTGR	modular high-temperature gas-cooled reactor
MIRD	Medical Internal Radiation Dose
MIS	Management Information Service
MIT	Massachusetts Institute of Technology
MODIL	Manufacturing Operations Development Integration Laboratory
MOU	memorandum of understanding
MRS	monitored retrievable storage
MS/MS	mass spectrometry/mass spectrometry
NASA	National Aeronautics and Space Administration
NAVFAC	Naval Facilities Engineering Command
NBS	National Bureau of Standards
NCI	National Cancer Institute
NCRP	National Council on Radiation Protection and Measurements
NCSASR	National Center for Small-Angle Scattering Research
NCTR	National Center for Toxicological Research
NDE	Nondestructive evaluation
NEESA	U.S. Naval Energy and Environmental Support Activity
NEPA	National Environmental Policy Act

NERP	National Environmental Research Park
NG	newly generated
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
NLM	National Library of Medicine
NOAA	National Oceanic and Atmospheric Administration
NPR	New Production Reactor
NRC	Nuclear Regulatory Commission
NSCANS	National Steering Committee for the Advanced Neutron Source
NSF	National Science Foundation
NSLS	National Synchrotron Light Source
NTP	National Toxicology Program
NUSC	Naval Underwater Systems Center
OASD	Office of Assistant Secretary of Defense
OCRWM	Office of Civilian Radioactive Waste Management
OEA	Office of Environmental Analysis
OER	Office of Energy Research
OFE	Office of Fusion Energy
OHER	Office of Health and Environmental Research
OJCS	Organization of Joint Chiefs of Staff
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 Research Reactor
ORTA	Office of Research and Technology Applications
OSHA	Occupational Safety and Health Administration
PCB	polychlorinated biphenyl
PETC	Pittsburgh Energy Technology Center
PNC	Power Reactor and Nuclear Fuel Development Corporation (Japan)
PPPL	Princeton Plasma Physics Laboratory
PWR	pressurized water reactor
RADCAL	Radiation Calibration Laboratory
R&D	research and development
RAM	Reliability, Availability, and Maintainability
RAP	Remedial Action Program
RCRA	Resource Conservation and Recovery Act
RCS	Residential Conservation Service
REDC	Radiochemical Engineering Development Center
RERTR	Research Enrichment Research and Test Reactor
REST	Residence in Science and Technology
rf	radio frequency
RFTF	Radio Frequency Test Facility
RH	remotely handled
RIMS	Resonance Ionization Mass Spectrometry
RISC	Radiation Shielding Information Center

RISP	Robotics and Intelligent Systems
RPP	Radiochemical Processing Plant
RRAC	Reactor Review and Audit Committee
RSIC	Radiation Shielding Information Center
RTG/DIPS	Radiation Thermoelectric Generator/Dynamic Isotope Power System
SAR	Safety Analysis Report
SAS	Strategic Alternatives Study
SCSS	Sequence Coding and Search System
SCUU	Southern College University Union
SDI	Strategic Defense Initiative
SDI-EPRI	Strategic Defense Initiative-Electric Power Research Institute
SDIO	Strategic Defense Initiative Organization
SDP	Site Development and Facilities Utilization Plan
SDT	Space and Defense Technology
SEED	Summer Educational Experience for the Disadvantaged
SEMATECH	Semiconductor Manufacturing Technologies
SERS	surface-enhanced Raman scattering
SFI	Strategic Facilities Initiatives
SFMP	Surplus Facilities Management Plan
ShaRE	Shared Research Equipment
SIRIS	Sputter Induced Resonance Ionization Spectroscopy
SMAC/CRC	Surface Modification and Characterization Collaborative Research Center
SPC	Superconductivity Pilot Center
SSC	superconducting super collider

STX	Spherical Torus Experiment
SWSA	solid-waste storage area
TEXTOR	Tokamak Experiment for Technical Oriented Research
TFTR	Tokamak Fusion Test Reactor
TIP	Toxicology Information Program or Technology Internship Program
TOPS	Transportation Operational Personnel Property Standard System
TPP	Transuranium Processing Plant
TRU	transuranic
TSR-II	Tower Shielding Reactor-II
TSRV	Torpedo Silencing Research Vehicle
TURF	Thorium-Uranium Recycle Facility
TVA	Tennessee Valley Authority
UCLA	University of California at Los Angeles
UKAEA	United Kingdom Atomic Energy Authority
ULCP	University Laboratory Cooperative Program
UMTRAP	Uranium Mill Tailings Remedial Action Project
USDA	U.S. Department of Agriculture
U.S.S.R.	Union of Soviet Socialist Republics
UTK	The University of Tennessee, Knoxville
VISITS	Very Important Small Institution Travel Support
VMT	vehicle miles of travel
VPI	Virginia Polytechnic Institute
WIPP	Waste Isolation Pilot Plant
WMTC	Waste Management Technology Center
WSDD	Waste Systems Data and Development

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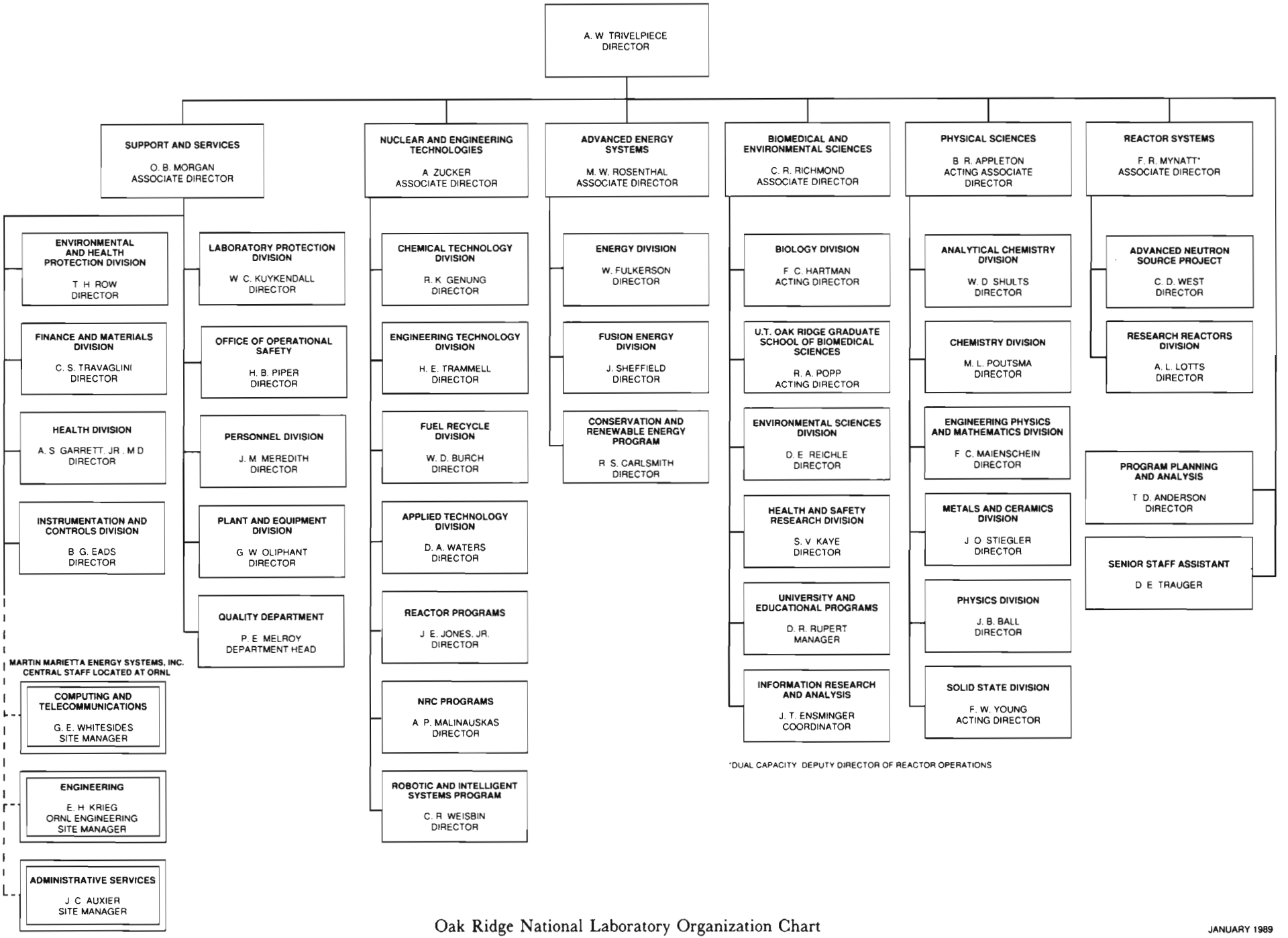

Oak Ridge National Laboratory Organization Chart

JANUARY 1989

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