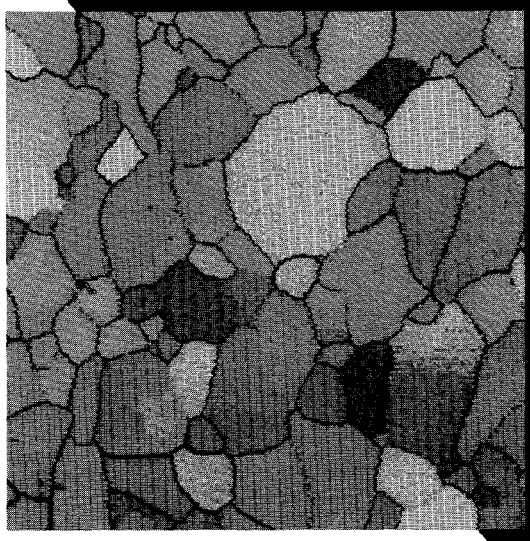
Oak Ridge National Laboratory



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Institutional Plan
FY 1997 – FY 2002

Oak Ridge National Laboratory is managed for the U.S. Department of Energy by Lockheed Martin Energy Research Corporation

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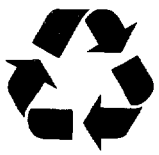
Cover image:

ORNL's new RABiTS™ process (for rolling-assisted biaxially textured substrates) offers great promise for the development of practical applications for high-temperature superconducting materials. With RABiTS, these materials can be fabricated into wire or tape for winding electric motors, generators, transformers, or other applications that involve substantial magnetic fields.

This microscopic image shows grain boundaries in a RABiTS substrate. The thickness of the lines between grains indicates the alignment of adjacent grains—the thinner the line, the smaller the misorientation angle. High grain alignment, like that shown here, provides excellent superconducting performance. The RABiTS process was developed through a multidisciplinary effort by ORNL physicists, materials scientists, and chemists, supported by funding from the Department of Energy's Office of Energy Research and Office of Energy Efficiency and Renewable Energy.

Image created by Amit Goyal, ORNL Metals and Ceramics Division



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Oak Ridge National Laboratory Institutional Plan

FY 1997–FY 2002

October 1996

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Oak Ridge, Tennessee 37831-6285
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1 • Laboratory Director's Statement

The Oak Ridge National Laboratory (ORNL) entered a new era on January 1, 1996, as Lockheed Martin Energy Research Corporation became ORNL's management and operating contractor. This new arrangement provides both additional responsibilities and enhanced opportunities. For example, we are responsible for managing and operating ORNL in a manner consistent with its purposes and functions as a Federally Funded Research and Development Center, and we have the opportunity to demonstrate enhanced performance by reducing the cost of doing business and improving our efficiency in conducting research and development (R&D) while maintaining a safe working environment.

In working to take full advantage of this change in the Laboratory's situation, we have undertaken the process of reengineering ORNL, with the aim of meeting the Department's expectations for programmatic and operational excellence in the most cost-effective way. This effort is directed toward providing

- a corporate structure for ORNL that supports, and is responsive to, the R&D mission,
- a working environment that ensures maximum scientific productivity and rewards for individual and team efforts,
- operating policies and controls that use "Work Smart" standards to ensure highest-quality R&D performance in compliance with all applicable requirements, and
- "Best Industry Practices" support and services to R&D programs at minimum cost.

In parallel with this reengineering effort, we are developing new relationships with the Department, new ways of doing business, and new directions for R&D. All of these are described in this institutional plan.

Staff members in the Department's Oak Ridge Operations Office are participating in ORNL's reengineering. Initiatives undertaken by the Department—such as contract reform, strategic alignment, accelerated review of directives, and oversight pilots—have created opportunities for ORNL and Department staff to work together. A set of partnering principles, established in January 1996 by the Laboratory and the Oak Ridge Operations Office, demonstrates the new focus on outcome-based management.

Another factor in this transformation is the *Strategic Laboratory Missions Plan—Phase 1* recently released by the Department's Laboratory Operations Board. The plan is aimed at enhancing the focus and increasing the effectiveness of the national laboratories. The vision and mission that it outlines for these institutions provide additional guidance to our efforts to position ORNL to deliver science and technology-based solutions that serve the Department's missions.

Three major initiatives, described in detail in Sect. 4 of this Institutional Plan, are proposed to strengthen ORNL's ability to support the missions of the Department: neutron science, functional genomics, and distributed computing at teraflop speeds.

- **Neutron science.** Neutrons play a vital role in many areas of science and technology. They provide an ideal probe of the structure and dynamics of condensed matter; they are useful in the study of magnetic structure and dynamics; and, because they are highly penetrating, they can be used to study bulk materials nondestructively, an application of obvious interest for industry. The ability of neutrons to transmute matter leads to invaluable applications such as the production of isotopes and neutron activation analysis. Neutron science is one of ORNL's R&D competencies, with roots in the Laboratory's original mission. ORNL proposes to apply its strengths in this area to national needs through modernization of the High Flux Isotope Reactor to maintain and extend its unique capabilities for some classes of neutron scattering experiments and for neutron activation analysis, through leadership of the Department's National Spallation Neutron Source project, and through collaboration with the state of Tennessee in establishing a Joint Institute for Neutron Science.
- **Functional genomics.** The Human Genome Project is approaching its goal of analyzing the structure of human DNA and determining the location of the estimated 100,000 human genes. The next phase of this program will move beyond mapping and sequencing to linking the location and structure of genes to the functions that they control. ORNL proposes a major Laboratory initiative in functional genomics, combining its long-standing expertise in mammalian genetics with its capabilities in structural biology, computational science, robotics, and instrumentation to accelerate the exploration of gene function. Integration of the expertise of molecular biologists, computer scientists, mathematicians, analytical chemists, and engineers should provide highly productive experimental capabilities and technological breakthroughs for genetics research.
- **Distributed computing at teraflop speeds.** The use of computational tools is vital to most fields of science and engineering. These tools enable the creation of realistic models of physical situations, providing new insights into the properties of materials, the effects of human activity on the earth's climate, the structure of the human genome, and a host of other basic and applied problems. Computers operating in the trillions of floating point operations (teraflop) range will be needed to support both national security needs and advances in science and technology. No single computer with such capabilities currently exists. ORNL proposes to collaborate with the Department's Sandia National Laboratories in linking two 10-teraflop computers, one to be located at each institution, and applying the resulting 20-teraflop "distributed computer" to scientific problems that require the full power of this system.

These initiatives are notable for their emphasis on collaboration at many levels. They require integration, cooperation, and partnerships across a range of scientific disciplines; throughout the Department's system of national laboratories; among federal agencies; and with local, state, and national entities.

We believe that this spirit of collaboration will continue to characterize all of our activities, both programmatic and operational, as we build on ORNL's historic strengths, deliver scientific and technological value to the Department, and establish ORNL as an efficient, cost-effective institution that is highly regarded for its excellence, ethics, and integrity.

2 • Laboratory Missions

Mission Statement

The Oak Ridge National Laboratory (ORNL) is a Department of Energy multiprogram laboratory. It is managed for the Department by Lockheed Martin Energy Research Corporation. The mission of the Laboratory is to conduct basic and applied research and development (R&D) in order to advance the nation's energy resources, environmental quality, and scientific knowledge and to contribute to educational foundations and national economic competitiveness.

Operational Imperatives

In carrying out its missions for the Department of Energy, ORNL is governed by the following operational imperatives:

- Adhere to the highest professional and ethical standards in all research and business activities.
- Support the execution of R&D missions with efficient, cost-effective business practices and support services.
- Acquire and sustain the intellectual and physical resources needed to explore challenging scientific and technical problems and provide innovative solutions.
- Conduct all operations in a safe and environmentally responsible manner.
- Collaborate with universities, industry, other Department of Energy laboratories, other federal agencies, and state and regional organizations to create new opportunities.
- Communicate the value of ORNL's R&D activities to a broad audience.
- Respect the value of other people's time.

Mission Roles

The *Strategic Laboratory Missions Plan—Phase 1** describes mission roles for the Department's national laboratories. As a multiprogram laboratory, ORNL is involved in all

*Available from the Office of Public Affairs, CP-41, U.S. Department of Energy, 1000 Independence Avenue SW, Washington, DC 20585, or at <http://www.doe.gov/html/doe/whatsnew/labmsspl/summary.html> on the World Wide Web.

four of the Department's major missions: science, energy resources, environmental quality, and national security. The Laboratory's principal roles are in fundamental science and energy resources. Special capabilities support the Department's needs in environmental quality and national security. ORNL is a primary performer of R&D in energy efficiency, environmental science and technology, nuclear physics, biological sciences, and basic energy sciences.

Mission Execution

To execute its missions, ORNL applies a set of R&D competencies characterized by an integration of technical foundations in physical, chemical, and materials sciences; biological, environmental, and social sciences; engineering sciences; and computational sciences and informatics. The ability to integrate broad technical foundations to develop and sustain R&D competencies in support of national goals is a distinguishing strength of the national laboratories. ORNL's R&D competencies are

- energy production and end-use technologies,
- biological and environmental sciences and technology,
- advanced materials synthesis, processing, and characterization,
- neutron-based science and technology,
- computational science and advanced computing, and
- instrumentation, manufacturing, and control technologies (an emerging R&D competency shared with the Oak Ridge Y-12 Plant).

Four distinguishing institutional competencies cross-cut the R&D competencies and the technical foundations and are important characteristics of the Laboratory as a whole:

- development and operation of national research facilities,
- R&D integration and partnerships,
- technology transfer, and
- science education.

Mission Profile

In support of the Department's development of the *Strategic Laboratory Missions Plan—Phase 1*, ORNL provided a Laboratory mission profile that summarizes its major facilities, key R&D activities, funding history, relationship to the Department's missions, and key collaborations with other R&D performers. This profile is reproduced in Table 2.1.

Table 2.1
ORNL mission profile

Laboratory Information

Name:	Oak Ridge National Laboratory
Location:	Oak Ridge, TN
Contractor:	Lockheed Martin Energy Research Corp.
Budget:	$545 million (FY 95)

DOE Programs

Energy Research, Environmental Management, Energy Efficiency and Renewable Energy, Nuclear Energy, Defense Programs, Environment, Safety, and Health, Fossil Energy

Description

Oak Ridge National Laboratory (ORNL) is a multiprogram laboratory focusing on national and global energy and environmental issues. Founded in 1943, ORNL pioneers the development of new energy sources, technologies, and materials and the advancement of knowledge in the biological, chemical, computational, engineering, environmental, physical, and social sciences. ORNL's mission is to conduct basic and applied research and development in order to advance the nation's energy resources, environmental quality, and scientific knowledge and to contribute to educational foundations and industrial competitiveness.

Major Facilities

High Flux Isotope Reactor: World's highest neutron flux; isotopes for industry, medicine, and research; excellent source of neutrons for condensed matter investigations

Holifield Radioactive Ion Beam Facility: First U.S. radioactive ion beam facility devoted to low-energy nuclear structure and nuclear astrophysics research

Mouse Genetics Facility: Houses 200,000 mice; unique strains including lines developed to model human diseases

High Temperature Materials Laboratory: Collaborative research on advanced ceramics and alloys; extensive capabilities for materials characterization

Oak Ridge National Environmental Research Park: Total of 21,500 acres for environmental research and education, including protected eastern deciduous forest

Center for Computational Sciences: Intel Paragon XP/S 150 is among world's most powerful computers

Buildings Technology Center: Provides the U.S. buildings industry with broad access to a unique collection of testing and analysis capabilities

Key Research and Development Activities

Science and Technology

Materials science and engineering: high-temperature intermetallic alloys and advanced ceramics

Neutron science: neutron source design, neutron scattering, neutron activation analysis

Analytical and separations chemistry

Biomedicine, biotechnology, and genetics research

Nuclear physics and astrophysics with radioactive ion beams

Energy Resources

Energy-efficient technologies for buildings, industrial, transportation, and utility end-use

Biomass: renewable energy feedstock and conversion technology

Fossil fuel: applied materials and turbines

Fusion science and technology

Nuclear technology and safety

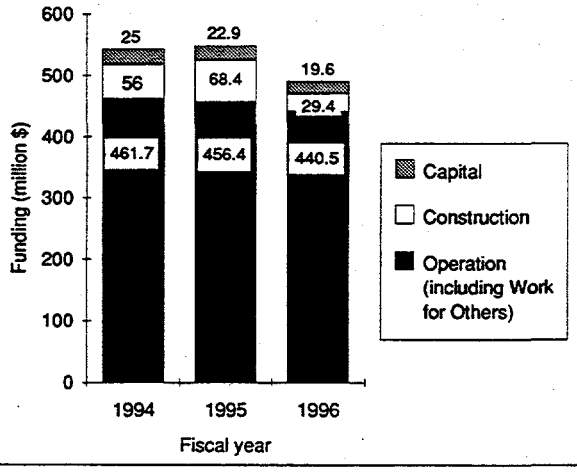
Environmental Quality

Health effects of energy-related substances

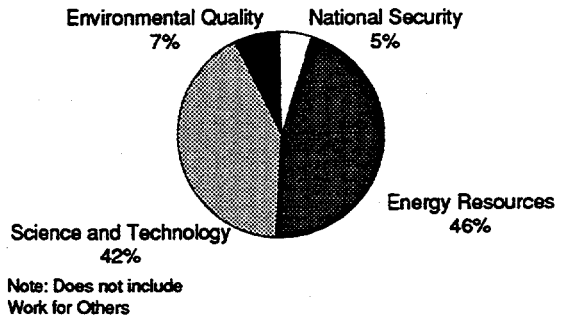
Environmental systems, risk assessment, and technology

World climate and carbon data analysis for international community

Funding History



Operating Budget Summary



Note: Does not include Work for Others

Table 2.1
(continued)

Distinctive Competencies
Integration of basic and applied R&D with broad partnership base: biological, environmental, and social sciences; physical, chemical, and materials sciences; engineering science; computational science and informatics
Extensive high-performance computing capability with specific application to modeling and simulation of complex systems
Socioeconomic and technology impact analysis and R&D for sustainable development
Advanced instrumentation (biological, chemical, nuclear): electronics, photonics, imaging, and signal processing
Control, robotics, and manufacturing technologies

Partnerships and Collaboration
ORNL's programs are characterized by extensive collaboration. ORNL interacts with many other Department of Energy national laboratories. Research contracts are in place with more than 100 universities from more than 35 states. More than 1000 companies and representatives from more than 80 countries also collaborate with ORNL. More than 70 percent of ORNL's journal publications are co-authored with other institutions. • In FY 1995, ORNL hosted more than 4000 guests (those staying two weeks or longer), including 1600 from industry. ORNL's 14 user facilities provide the focus for many interactions. • ORNL has more than 220 cooperative research and development agreements with partners ranging from large corporations to small companies, with a dollar value exceeding $200 million. Multiorganization ventures include the following: – The Partnership for a New Generation of Vehicles is a cooperative venture involving seven Federal Agencies and the Big Three auto makers. – The American Textile Partnership involves ten national laboratories; ORNL is the lead laboratory for Computer Aided Fabric Evaluation and On-Line Process Control. – The High Temperature Superconductivity Consortium has resulted in 35 collaborative agreements, generating $17 million in program cost sharing from industry. – Industries of the Future involves partnerships with the chemical, pulp and paper, metals, glass, and petroleum refining industries. – The Buildings Technology Center has established industry-wide partnerships to develop advanced heat pumps and chlorine-free refrigerants, and to test components of the building envelope. • ORNL places a strong emphasis on regional collaboration. ORNL and the University of Tennessee are partners in the Science Alliance, and joint institutes covering both research and education exist for computational science, heavy ion research, energy and environment, and molecular-based engineering and science. Other regional partners include the Knoxville Police Department, the Tennessee Valley Authority, the Oak Ridge Institute for Science and Education, the Appalachian Regional Commission, minority educational institutions, and area primary and secondary schools. For example, a partnership with a local cancer research center produced a laser technique for nonsurgical biopsy. • The Oak Ridge Centers for Manufacturing Technology—itself a collaborative effort with the Oak Ridge Y-12 Plant—responded to over 380 requests for technical assistance in FY 1995 and provided training for more than 5000 workers. • ORNL carries out research for the Department of Defense (all branches), the Departments of Transportation and Health and Human Services, the Environmental Protection Agency, NASA, the Nuclear Regulatory Commission, the National Science Foundation, and other government agencies. Interagency partnerships in global climate change research and high-performance computing and communications also draw on ORNL's capabilities. • International partners include the European Union, Japan, and Russia. Major programs include the IEA-sponsored Atomic Data Center, the IAEA-sponsored Nuclear Data Center, the Radiation Shielding Information Center, and engineering design activities for the International Thermonuclear Experimental Reactor. Important collaborations exist with the European Spallation Source, Japan Atomic Energy Research Institute, and Korea Atomic Energy Research Institute.

Table 2.1
(continued)

Significant Accomplishments
Atomic Imaging: Using the *Z*-contrast imaging technique developed at Oak Ridge National Laboratory in combination with the world's highest-resolution scanning transmission electron microscope, researchers have produced the first direct images of the structure and chemical identity of atoms at critical regions inside solids. Unexpected structures for grain boundaries in semiconductors, ceramics, and superconductors have been discovered. This brings unique insights into the macroscopic properties of these materials and points the way to methods for engineering improvements. This technique is applicable to a vast range of advanced materials, including structural and high-temperature materials, optical and electronic materials, and magnetic materials.
High-Temperature Superconductors: A process developed at Oak Ridge produces substrates for practical superconducting wires with record high critical current density. The process, called RABiTS, uses low-cost textured metal substrates in combination with thin-film superconductors to produce superconducting tapes. An yttrium-barium-copper oxide tape produced using RABiTS had a measured critical current density of 700,000 amperes per square centimeter at a temperature of 77 kelvin. (For comparison, standard household wires typically carry less than 1,000 amperes per square centimeter.) This performance far exceeds that of bismuth-based powder-in-tube wires and is most important for applications in transformers, motors, and generators.
High-Temperature Materials Development: Basic and applied research at Oak Ridge has led to the development of two new classes of structural materials—whisker-toughened ceramics and ductile intermetallic alloys—and to new processes and products with significant economic impact. Whisker-toughened ceramics are now sold as cutting tools and beverage-can die assemblies. Gelcasting, a process for making high-quality ceramic parts in complex shapes, is used in manufacturing turbine rotors, thermal insulation for engine exhaust manifolds, and magnet rings for particle accelerators. The Exo-Melt process saves time and energy in the manufacture of nickel aluminides (used for furnace equipment such as trays, belts, and rollers) and iron aluminides (used for hot-gas filters and heating elements). A ceramic composite filter developed in collaboration with the 3M Company is lighter, more reliable, and more efficient than conventional filters in removing particulates from hot gas streams in fluidized-bed combustion systems and coal gasification plants.
Biological and Environmental Research: Oak Ridge accomplishments in the biological sciences include an intelligent computer system, GRAIL, for identification of genes from DNA sequences; physical maps of regions of the mouse genome that correspond to the human genome; advanced techniques for detecting gene mutations; and mouse models for several human diseases. A new pathway for photosynthesis has been discovered, and advances have been made in cryopreservation. In environmental research, achievements include ecosystem studies of the impacts of climate change on forests; management of massive databases for global change research; and monitoring, assessment, and remediation of chemically contaminated ecosystems.
High-Performance Computing: Oak Ridge National Laboratory is one of the most powerful computing sites in the world, a leader in high-performance storage systems, and a focal point for the solution of complex problems in a variety of fields. The Intel Paragon computers of the Center for Computational Sciences are the focus for the development of advanced computational applications for scientific research and improvements in computing tools and technologies. The Laboratory has become a world leader in distributed computing research by developing algorithms, paradigms, and tools such as PVM (Parallel Virtual Machine) that permit a heterogeneous collection of computers to be used as a single large parallel computer.

3 • Laboratory Strategic Plan

In August 1995, the Oak Ridge National Laboratory (ORNL) issued the *ORNL R&D Strategic Plan.* The strategic planning process that was carried out in developing this plan included an analysis of the current situation, selection of an overall strategy for the future, and the definition of goals and strategies. These elements are summarized here.

Changes in ORNL's environment, as described in Sect. 1, mandate a heightened focus on strategic planning. The *Strategic Laboratory Missions Plan—Phase 1* and the forthcoming update to the Department of Energy's strategic plan will provide guidance to ORNL in planning for the future of the Laboratory.

3.1 • Vision

ORNL is committed to advancing the frontiers of science and technology while addressing important national and global energy and environmental needs.

The Laboratory strives to be so well recognized for its excellence that students in certain fields of science and engineering regard working at ORNL as an essential element in their education.

3.2 • Situation Analysis

For the purposes of this strategic plan, it is assumed that ORNL will remain a Department of Energy–owned, contractor-operated national laboratory and that its most important role will be providing support for the Department's missions. The Department of Energy will remain ORNL's primary sponsor. At the same time, a growing emphasis on making the resources of the national laboratories available to the entire government system—on making these institutions in fact, as well as in name, *national* laboratories—will broaden ORNL's customer base.

The Department of Energy has identified five "business lines"—science and technology, energy resources, environmental quality, national security, and economic productivity. Its primary missions are in the first four areas, with economic productivity representing a derivative and critical success indicator of these missions.

ORNL is positioned to supply the knowledge and technology that the Department needs to achieve its strategic goals in these areas. As a diversified laboratory with a broad

mission carried out by a multidisciplinary staff through several major program areas, ORNL will

- apply its scientific and technical capabilities to national needs by conducting basic and applied research in an integrated program that includes extensive collaboration with universities and industry;
- conceive, develop, and demonstrate safe, economical, reliable, and environmentally sustainable technologies for efficient energy supply and use;
- provide the knowledge and technology needed to sustain, protect, and restore the environment; to enhance human health; and to support practices and policies that promote sustainable development; and
- contribute to maintaining the technology infrastructure and capabilities needed to ensure national security.

ORNL has an experienced and talented staff and a remarkable array of research tools. These assets will be maintained, strengthened, and focused on creating and exploring the revolutionary changes expected in the fields of science and technology in which ORNL is involved. The exploration of new technical directions will be supported through the Laboratory Directed Research and Development Fund, which provides financial support for innovative ideas, and through program development activities.

Demand for the knowledge and technology that are ORNL's principal products is expected to remain high. However, constraints on federal funding, coupled with the end of the Cold War, have led to intense scrutiny of the Department of Energy and its national laboratories and to calls for changes in the organization and management of the national laboratory system, focusing on efficiency, relevance to national needs, and accountability. Implementation of these changes will have an impact on the future of ORNL.

The multidisciplinary character of the Laboratory will be maintained, although fiscal pressures will mandate concentration on areas of strength and integration of complementary capabilities across the national laboratory system. The Department's effort to sharpen the focus of its national laboratories in their mission roles, as documented in the *Strategic Laboratory Missions Plan—Phase 1,* represents an opportunity for ORNL to apply and leverage the strengths embodied in its research and development (R&D) competencies.

Integration across programmatic and organizational lines will be essential to the improved efficiency that will be demanded from the national laboratories. ORNL's institutional competency in R&D integration and partnerships represents a strength that will be of great value in coordinating resources at ORNL, within the Department of Energy's Oak Ridge complex, and across the national laboratory system. However, administrative and bureaucratic barriers to internal productivity and external collaboration must be addressed by the Laboratory and the Department.

Removal of these barriers is also a key to expanding the Laboratory's customer base. ORNL has an outstanding record in working with the private sector. More than 220 cooperative R&D agreements, more than 100 patent licensing agreements, and developments representing millions of dollars in jobs, products, and cost savings demonstrate the breadth of ORNL's institutional competency in technology transfer. In keeping with the Department's emphasis on economic productivity, ORNL will work to identify and attract new customers in government and industry.

The Laboratory's other institutional competencies—development and operation of national research facilities and science education—also support the emphasis on partnerships. In addition, they underlie a tradition of laboratory-university cooperation that will serve as a

foundation for continuing efforts to strengthen basic research and support national goals for world leadership in science, mathematics, and engineering.

In all of the Laboratory's activities, cost-effective operation and improved efficiency and resource management will become increasingly important as the availability of resources declines. The reengineering activities described in Sect. 7.1 are focused on reducing costs and increasing productivity. ORNL will continue to pursue creative solutions to replacing its aging infrastructure and resolving environmental "legacy issues," seeking input from stakeholders and applying technical innovations developed in its research programs.

3.3 • Strategy for the Future: Bringing Science to Life

As it advances into the 21st century, ORNL will seek new and creative ways to integrate its resources and apply them to the development of the science and technology needed to answer fundamental questions, solve technical problems, and address social needs. To extend the nation's capabilities in key areas of science and technology, ORNL proposes the following major initiatives, described in detail in Sect. 4 of this plan.

- **Neutron science.** Neutrons play a vital role in many areas of science and technology. They provide an ideal probe of the structure and dynamics of condensed matter; they are useful in the study of magnetic structure and dynamics; and, because they are highly penetrating, they can be used to study bulk materials nondestructively, an application of obvious interest for industry. The ability of neutrons to transmute matter leads to invaluable applications such as the production of isotopes and neutron activation analysis. Neutron science is one of ORNL's R&D competencies, with roots in the Laboratory's original mission. ORNL proposes to apply its strengths in this area to national needs through modernization of the High Flux Isotope Reactor to maintain and extend its unique capabilities, through leadership of the Department's National Spallation Neutron Source project, and through collaboration with the state of Tennessee in establishing a Joint Institute for Neutron Science.
- **Functional genomics.** The Human Genome Project is approaching its goal of analyzing the structure of human DNA and determining the location of the estimated 100,000 human genes. The next phase of this program will move beyond mapping and sequencing to linking the location and structure of genes to the functions that they control. ORNL proposes a major Laboratory initiative in functional genomics, combining its long-standing expertise in mammalian genetics with its capabilities in structural biology, computational science, robotics, and instrumentation to accelerate the exploration of gene function. Integration of the expertise of molecular biologists, computer scientists, mathematicians, analytical chemists, and engineers should provide highly productive experimental capabilities and technological breakthroughs for genetics research.
- **Distributed computing at teraflop speeds.** The use of computational tools is vital to most fields of science and engineering. These tools enable the creation of realistic models of physical situations, providing new insights into the properties of materials, the effects of human activity on the earth's climate, the structure of the human genome, and a host of other basic and applied problems. Computers operating in the trillions of floating point

operations per second (teraflop) range will be needed to support both national security needs and advances in science and technology. No single computer with such capabilities currently exists. ORNL proposes to collaborate with the Department's Sandia National Laboratories in linking two 10-teraflop computers, one to be located at each institution, and applying the resulting 20-teraflop "distributed computer" to scientific problems that require the full power of this system.

To foster the growth and health of a strong, flexible organization that is positioned to address important challenges, strategic goals have been defined in three broad areas.

- Institutional goals are directed toward maintaining the Laboratory's foundations, to ensure that ORNL possesses the strengths needed for current and future missions, and toward making these strengths available through partnerships, technology transfer, and education.
- Programmatic goals are directed toward mission execution. Goals are presented for five R&D competencies:
  - energy production and end-use technologies;
  - biological and environmental sciences and technologies;
  - advanced materials synthesis, processing, and characterization;
  - neutron-based science and technology; and
  - computational science and advanced computing.
- Operational goals have been established to reflect the Laboratory's commitment to excellence in its business practices. These goals address the critical success factors of the Department of Energy's strategic plan: environment, safety, and health; management practices; human resources; and communication and trust. Our aim is to operate ORNL in a manner that supports our mission, meets the expectations of our customers, expedites the performance of research programs, and is rewarding to our staff.

3.4 • Strategic Goals

3.4.1 • Institutional Goals: Laboratory Foundations

ORNL's institutional goals are closely linked to the science and technology goals of the Department's strategic plan. They are focused on the development and application of the technical foundations, R&D competencies, and institutional competencies identified through the Laboratory's strategic planning efforts.

Goal 1. Develop and enhance technical foundations and R&D competencies that support DOE missions.

Goal 2. Design, construct, and operate world-class user facilities.

Goal 3. Extend the Laboratory's resources to a broad customer base through partnerships, technology transfer, and science education.

3.4.2 • Programmatic Goals: Mission Execution

The Laboratory applies its R&D competencies to helping the Department achieve its missions. Abbreviations following each programmatic goal indicate the business lines that

the goal supports: S&T for science and technology, EN for energy resources, EQ for environmental quality, NS for national security, and EP for economic productivity. Many activities support multiple business lines, indicating ORNL's ability to integrate its strengths and address diverse challenges that transcend disciplinary boundaries.

3.4.2.1 • Energy Production and End-Use Technologies

Goal 1. Respond to changing national policies on fission energy and nuclear materials while maintaining a record of achievement and excellence in nuclear technology and safety R&D. (S&T, EN, NS)

Goal 2. Host the nuclear technology phase of the U.S. fusion program. (S&T, EN)

Goal 3. Develop and deploy innovative systems for the clean and efficient use of fossil, renewable, and alternative fuels. (S&T, EN, EQ, EP)

Goal 4. Improve the efficiency and reduce the environmental impact of systems for energy delivery and use. (S&T, EN, EQ, EP)

Goal 5. Develop and deploy new tools and technologies that lead to safe, sustainable transportation systems. (S&T, EN, NS, EP)

3.4.2.2 • Biological and Environmental Sciences and Technology

Goal 1. Advance fundamental understanding of the molecular basis of gene and protein function. (S&T, EN, EQ, EP)

Goal 2. Restore and enhance the capability for producing and separating isotopes for medical, industrial, and national research needs. (S&T, EQ, EP)

Goal 3. Reduce the risk to human health from exposure to hazardous chemicals and radionuclides, and improve human welfare through biomedical research. (S&T, EN, EQ)

Goal 4. Improve the understanding of environmental processes and develop a scientific basis for implementing environmental technologies (monitoring, mitigation, and remediation). (S&T, EN, EQ, EP)

Goal 5. Develop the scientific basis and deploy techniques for supporting socially and environmentally responsible technology development and options for sustainable development. (S&T, EN, EQ)

3.4.2.3 • Advanced Materials Synthesis, Characterization, and Processing

Goal 1. Develop, enhance, and promote the advanced materials synthesis, characterization, and processing competency to address national needs in energy, the environment, and economic competitiveness. (S&T, EN, EQ, EP)

Goal 2. Enhance partnerships in materials science R&D. (S&T, EN, EQ, EP)

Goal 3. Provide infrastructure to support world-class materials research. (S&T, EN, EQ, EP)

3.4.2.4 • Neutron-Based Science and Technology

Goal 1. Gain academic and industrial recognition of the Laboratory's neutron science facilities and capabilities as necessary and unique national assets. (S&T, EN, EP)

Goal 2. Strengthen and enhance ORNL's neutron-based science and technology programs to improve research excellence, collaborations, and relevance to a broad range of scientific disciplines. (S&T, EN, EQ, NS, EP)

Goal 3. Design, construct, and operate a high-power spallation neutron source to provide an unparalleled facility for neutron science and technology. (S&T, EN, EQ, EP)

3.4.2.5 • Computational Science and Advanced Computing

Goal 1. Build a world-class program in computational science. (S&T, EN, EQ, EP)

Goal 2. Create a high-performance computing and communication environment that supports the requirements of Grand Challenge research. (S&T, EP)

Goal 3. Expand fundamental research in advanced computational methods for distributed nonlinear systems at the Center for Engineering Systems Advanced Research, with emphasis on intelligent systems (e.g., cooperating robots and smart sensors) and on geophysical applications. (S&T, EN, NS, EP)

Goal 4. Assist industry in the application of computing to analysis, design, and manufacturing. (S&T, EP)

Goal 5. Develop and deploy numerical algorithms for solving large-scale scientific and engineering problems. (S&T, EN, EQ, EP)

Goal 6. Advance the use of high-performance computing and communications in university and precollege educational programs. (S&T, EP)

3.4.3 • Organizational Effectiveness

Operational goals have been established to reflect the Laboratory's commitment to excellence in its business practices. These goals address the critical success factors of the Department of Energy's strategic plan: environment, safety, and health; management practices; human resources; and communication and trust.

Goal 1. Conduct all operations in a safe and environmentally responsible manner.

Goal 2. Significantly reduce the cost of doing business by using best business practices.

Goal 3. Revitalize the Laboratory infrastructure.

Goal 4. Recruit and retain the staff needed to achieve programmatic goals.

Goal 5. Improve ORNL relationships with internal and external customers.

4 • Major Laboratory Initiatives

To extend the nation's capabilities in key areas of science and technology, ORNL proposes major initiatives in neutron science, functional genomics, and distributed computing. These initiatives are provided for consideration by the Department of Energy (DOE). Inclusion in this plan does not imply DOE approval of or intent to implement an initiative.

4.1 • Neutron Science

Neutrons play a vital role in many areas of science and technology. They provide an ideal probe of the structure and dynamics of condensed matter; they are useful in the study of magnetic structure and dynamics; and, because they are highly penetrating, they can be used to study bulk materials nondestructively, an application of obvious interest for industry. Additionally, the ability of neutrons to transmute matter leads to invaluable applications such as the production of isotopes for use in medical, industrial, and military applications, and neutron activation analysis for environmental, commercial, and forensic analyses.

ORNL's R&D competency in neutron science is an integrated capability that spans programs across the entire laboratory. This capability dates from the 1940s and has included many facilities over the years. Two major in-house facilities at present are the High Flux Isotope Reactor (HFIR) and the Oak Ridge Electron Linear Accelerator (ORELA) pulsed neutron source. The HFIR supports world-class research, production, and testing programs in neutron scattering, neutron activation analysis, isotope production, and material irradiation testing. ORELA now concentrates on nuclear astrophysics and basic neutron properties (e.g., neutron electric polarizability) research, but it is also available for other applications, such as target experiments for the proposed National Spallation Neutron Source (NSNS), and as a positron beam facility.

In addition to neutron sources, facilities supporting ORNL's broad neutron science programs include the Radiochemical Engineering Development Center, the Radioisotope Development Laboratory, the Transuranium Research Laboratory, and the Irradiated Fuels Examination Laboratory. The calutrons of the Isotope Enrichment Facility separate stable isotopes for use by outside researchers and can also make feedstock for radioisotope production. Neutron activation analysis capabilities are essential to a wide range of research (including medical and historical research) and operational projects (including pollutant detection and tracing) for customers inside and outside ORNL.

ORNL proposes a major initiative to ensure that the Laboratory continues its stewardship of neutron science in support of DOE's science mission. This initiative incorporates the following activities:

- Upgrades and refurbishment of the HFIR, which would make the HFIR the most powerful research reactor in the world and greatly enhance the Laboratory's already unique neutron science capabilities and programs.
- Design of the NSNS, a next-generation spallation neutron source facility being designed for DOE in collaboration with four other DOE national laboratories.
- Establishment of a Joint Institute for Neutron Science, in cooperation with the University of Tennessee, to accommodate the 1000 to 2000 users expected each year from universities, U.S. industry, and other laboratories.

4.1.1 • High Flux Isotope Reactor Upgrade

The HFIR is one of the world's most important and powerful research reactor facilities. Its thermal neutron flux of 2.3×10^{15} $cm^{-2} \cdot s^{-1}$, highest in the western world, makes it uniquely capable of producing important radioisotopes and providing facilities for materials irradiation, neutron activation analysis, and neutron beam scattering studies.

The proposed NSNS (see Sect. 4.1.2) will serve many of the needs of the neutron scattering research community and provide significant improvements over the existing beam scattering facilities at the HFIR for many experiments. However, the HFIR will remain the facility of choice for some classes of scattering experiments requiring steady-state beams and for radioisotope production, materials irradiation, and neutron activation analysis.

To continue these missions, upgrades are needed at the HFIR to modernize some of its instruments and components, to add new capabilities, to increase the reactor power level, and to maintain or improve the availability of neutrons to researchers. The complete HFIR upgrade would

- return the HFIR to 100-MW operation and improve operations;
- add a cold neutron source and an experimental guide hall;
- add five thermal beam guides, a thermal neutron guide hall, and new instrumentation;
- improve user access; and
- improve isotope production, materials irradiation, and neutron activation analysis capabilities.

The HFIR has been in operation for 30 years, and many of its control instruments and components are increasingly difficult to repair. Spare parts are scarce and sometimes impossible to find, and vendors no longer manufacture some of these components. In some cases, new technologies have led to more reliable, more accurate components that could reduce error margins and thereby enhance reactor safety and efficiency. Although many major components have been (or will soon be) replaced or refurbished, remaining minor instruments and components are based on technology that is now over 30 years old. Thus, replacing some of these instruments and components is both desirable and cost-effective.

The addition of a cold neutron source to the HFIR will provide capabilities as good as or better than those of the best cold neutron sources in the world for fundamental and applied research programs. These capabilities could provide the key to new discoveries and applications for plastics, alloys, and biochemical systems. As a complement to the NSNS, they will address important needs of the neutron scattering research community.

The addition of 5 thermal neutron guides at an existing beam port (called HB-2) will bring neutrons from close to the reactor out into a hall that will provide space for up to 15 experiments. Neutron guides work exactly like fiber-optic guides—they are rectangular conduits, typically 5 cm × 20 cm (2 in. × 8 in.), whose inside surfaces may be coated with one or more layers of material that will reflect any neutrons that strike the surface at a glancing angle, if they are not traveling too fast. Thus, the guides can bring neutrons from close to the reactor, in a series of ricochets, to an instrument more than 30 m (100 ft) away, with little loss. This capability is important for two reasons: first, it provides more space for instruments (only a very few of the big scattering spectrometers can be accommodated near the reactor). Second, near the reactor there is considerable background radiation, including gammas and fast neutrons, that tends to swamp the small signals that the researchers are looking for; because each guide reflects only rather slow neutrons, most of this undesirable background radiation escapes through guide walls, to be absorbed by shielding, before reaching the experimental sample and the detector.

The HFIR already has the world's most intense continuous beams of thermal neutrons, and this part of the upgrade will provide thermal neutron beams that are several times brighter than the best in the world. It will also increase the number of users that can be accommodated by increasing the number of beams and instruments. Office and laboratory space will be provided for outside users and for ORNL researchers.

Adding two or three hydraulic access tubes and making other changes to improve access for radioisotope production are important elements of an expanded ORNL isotopes program. The HFIR has two neutron activation analysis pneumatic "rabbit" tubes, but the current facility is limited in the volume of the sample that can be irradiated. A new design will accept larger samples or even multiple samples in each rabbit. In addition, provisions for delayed neutron counting will be added.

With these improvements, the HFIR can continue to operate for 25 years or more and will provide an important resource for neutron-based science.

4.1.2 • National Spallation Neutron Source

Neutron science is one of the few remaining areas where new scientific breakthroughs are limited by the intensity available from the source. Synchrotrons and lasers have largely removed this limitation for light and X rays, but neutrons, as vital as they are for so many areas of science, are severely intensity limited. The need for a new, intense source of neutrons is urgent, and because it will take at least six years to design and construct such a source, it is essential to start now to meet the nation's future needs in neutron science.

Neutrons used in scientific research are produced in two ways. The more familiar way occurs in nuclear reactors and is called fission. Within a nuclear reactor, enough uranium is brought together to sustain a controlled nuclear chain reaction that produces excess neutrons, which can be used for research. The second method, called spallation, produces neutrons when a target made up of atoms having massive nuclei is bombarded by energetic protons from a high-energy accelerator. When a proton smashes into the target nuclei, neutrons are ejected as a result of nuclear reactions initiated by the incident proton. Each high-energy proton in these spallation reactions typically releases 20 to 30 neutrons. These neutrons have energy distributions similar to those from a fission reaction, and they can be moderated and guided into an experimental area for research.

DOE has worked closely with the science community since the early 1970s in planning for the future needs for neutron sources. In 1996, DOE's Basic Energy Sciences Advisory Committee (BESAC) strongly reaffirmed the need for a next-generation, pulsed spallation neutron source to meet the future needs of the scientific community. This assessment follows closely on the heels of a 1993 BESAC study, *Neutron Sources for America's Future,* which provided a comprehensive assessment of the needs and options for new neutron facilities that would provide the United States with sources competitive with those now in operation in Europe and Japan. This study also eloquently summarized the broad uses and future opportunities for neutrons in science and technology.

The 1996 BESAC report recommended design of an accelerator-based spallation neutron source that could begin operation at a beam power of approximately 1 MW but with sufficient flexibility that it could be upgraded to significantly higher power in the future to meet the continually growing needs for an intense source. The report also recommended that the source be highly reliable and have high availability for the neutron user community.

In response to this national need, DOE provided $500,000 to ORNL in FY 1995 for initial scoping studies on the spallation neutron source. In the FY 1996 budget, DOE recommended and Congress appropriated $8 million to begin work on this new source. DOE directed the funds to ORNL to initiate research and development (R&D) and a conceptual design.

To accomplish this task, the Laboratory has organized a collaborative design effort involving ORNL, Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Ernest Orlando Lawrence Berkeley National Laboratory (LBNL), and Los Alamos National Laboratory (LANL). Other laboratories, U.S. industrial firms, and universities will be involved as the project matures. This collaborative approach was taken to access the best technical expertise available, to initiate a conceptual design process that made the most efficient use of the DOE work force and resources, to incorporate a number of previous feasibility studies by the collaborating laboratories, and to consolidate community consensus. In addition, memoranda of understanding have been signed with the European Spallation Source and several European laboratories to access research results and technology developments that could further leverage the NSNS design effort. BNL, LANL, and LBNL are responsible for the accelerator system design, which will be coordinated by an accelerator design group at ORNL. ORNL is responsible for the coordination, installation, and operation of the new source; for project management; for conventional construction; for target design; and—with ANL—for experimental systems design. The goal of the NSNS collaboration is to complete the conceptual design in time for a line-item request to DOE for FY 1998.

The reference design proposed for the NSNS consists of a high-energy linear accelerator (linac) injecting into an accumulator ring that produces short bursts of protons at extremely high energies and power levels. These proton pulses would be directed onto a heavy metal target where, through the spallation process, neutrons would be produced, moderated, and guided into experimental areas for use in a wide variety of experiments. The conceptual design of the NSNS will take two years to complete. The total cost of the facility will be about $1 billion, and it should be in operation by the year 2003. The NSNS will produce the highest-flux pulsed neutron beams in the world. It is estimated that the facility will attract 1000 to 2000 scientists and engineers each year from universities, industries, government laboratories, and other nations.

The reference design is consistent with the recommendations of the 1996 BESAC panel. The approach is to design a 5-MW spallation source that can be built in stages. The

first stage will be a 1-MW source that can be upgraded to 5 MW in the future, as funds allow. The target, moderator, and experimental systems provide for cold and thermal neutrons servicing 18 beam lines. International workshops have been held to gain input for the target design and to select the proper radiation-resistant materials. An NSNS Neutron Users' Workshop will be held in October 1996 to establish the desirable operating parameters and instrument designs that best meet the users' needs.

When completed, the NSNS will provide the most intense beams of neutrons in the world. The NSNS is designed to make future upgrades to higher powers extremely cost-effective, so that the United States should be able to stay at the forefront of neutron science for many years to come.

4.1.3 • Joint Institute for Neutron Science

ORNL, the University of Tennessee (UT), and the state of Tennessee have initiated plans for a Joint Institute for Neutron Science. This facility will enhance the utility of the NSNS and the HFIR by providing meeting facilities, offices, laboratories, a communication center, and housing for scientists and engineers from universities, industries, and the international community. It will also be a focus for expanding neutron science R&D with UT, other regional universities, and industrial collaborators and will serve as an interface and economic development gateway for outside access to ORNL's neutron science facilities. Funds were included in the state of Tennessee's FY 1996 budget to begin design of the Joint Institute for Neutron Science.

4.2 • Functional Genomics

Extraordinary advances in biomedical research have placed within our grasp a higher-order understanding of how genes function—that is, a correlation of specific genes with specific life processes. When the sequencing and mapping of the human genome are complete early in the next decade, we will have an extensive directory of the names and locations of the roughly 100,000 genes on human chromosomes. We will know very little, however, about the function of genes in vivo as orchestrated through their encoded proteins.

A new strategic plan for genome research, prepared by DOE's Office of Health and Environmental Research (OHER), outlines DOE's role in the next phase of the Human Genome Program as it moves beyond mapping and sequencing to linking the location and structure of genes to the functions that they control. ORNL is establishing a major Laboratory initiative in functional genomics as a means of focusing its unique resources to support this strategic plan.

ORNL plans to combine its long-standing expertise in mammalian genetics with its capabilities in structural biology, computational science, robotics, and instrumentation to accelerate the exploration of gene function. Integration of the expertise of molecular biologists, computer scientists, mathematicians, analytical chemists, and engineers should provide highly productive experimental capabilities and technological breakthroughs for genetics research. Work will take place on several fronts.

The most direct and generally applicable approach to deciphering gene function in vivo is through perturbation—that is, mutagenesis—of genes, followed by characterization

and quantification of the biological consequences. Because most mouse and human genes are identical or very similar, the mouse provides the ideal surrogate for elucidating the function of human genes and for designing models of human genetic disorders.

During its 50-year history, ORNL has conducted pioneering research in radiation biology and chemical mutagenesis and, more recently, in the generation of transgenics and targeted mutations in mice. In the course of this research, approximately 1000 lines of mutant mice have been developed and are being maintained as breeding stocks in ORNL's "mouse house." These lines represent a unique resource for potentially characterizing and treating genetic afflictions and birth defects. The merits of applying mutagenesis to gene function issues have been demonstrated by the development of mouse models for polycystic kidney disease, type II diabetes, sickle cell anemia, cleft palate, hydrocephalus, epilepsy, immunological and neurological disorders, birth defects, and genetic-based obesity.

In planning the allocation of its Laboratory Directed R&D (LDRD) funds for FY 1997, ORNL established a gene and protein function category with two major objectives: (1) the development of new processes, equipment, and instrumentation to achieve highly efficient operation of a modern mammalian (mouse) research facility and (2) the development of new processes, techniques, equipment, and instrumentation to achieve a significant decrease in the time required to determine the function of genes and proteins. Expected products include a significant increase in the speed at which the genetic basis of mammalian disease and other inherited afflictions is discovered. This LDRD category is described in Sect. 6.3.1.2.

Because mutations in genes give rise to mutated proteins that must be isolated and characterized to determine their consequences in the body, ORNL's strong capabilities for analysis of protein structure and function will also be brought to bear on the functional genomics initiative. Mutated proteins encoded by relevant genes can also be generated in the laboratory, by chemical or genetic means. Protein engineering through recombinant DNA technology enables rational design of protein structure. This approach will enhance ORNL's ability to understand protein function and tailor the properties of proteins in animals and plants for use in medicine, industry, agriculture, and biotechnology.

ORNL's proficiency in analyzing the function of genes will be applied to mouse mutants created by means of genetic engineering (targeted mutagenesis) and chemical mutagenesis. As genetic engineering for mouse mutagenesis is automated, the rate of gene function characterizations can be significantly increased.

Additional resources available to support this initiative include the Intel Paragon XP/S 150 supercomputer, which can be used to analyze structure and sequences of the chemical building blocks of genes, and the High Flux Isotope Reactor, the world's most powerful research reactor and steady-state neutron source for determining the structure of biological molecules. The functional genomics initiative will also provide opportunities to enhance the educational programs offered through the Graduate School of Biomedical Sciences, a special cooperative activity with the University of Tennessee established in 1966.

ORNL's functional genomics initiative will support and functionally integrate the Laboratory's activities and resources, providing coordinated utilization of DOE's mouse genetics and mutagenesis capabilities in Oak Ridge to support efforts in functional genomics. It will also enhance ORNL's ability to attract talented scientists interested in exploring the frontiers of molecular genetics in pursuit of the genetic basis of human disease. As part of this initiative, ORNL will continue to seek a means of providing a new home for the

Laboratory's mouse colony, which is currently housed in aging facilities at the Oak Ridge Y-12 Plant.

The functional genomics initiative will sustain ORNL's tradition of success in the biological sciences, thereby serving the science mission of DOE and the needs of society. It will also facilitate interactions and partnerships in a variety of areas, such as nuclear medicine, structural biology, computational biosciences, and environmental biotechnology. ORNL's activities and plans in these areas are described in Sect. 5.1.1.8. Such collaborations—not only among ORNL staff, but also with investigators from other federal laboratories, industry, and southeastern universities—are a key to success in developing the new capabilities needed in determining the function of genes.

By supporting ORNL's functional genomics initiative, DOE has the opportunity to enhance its scientific leadership in the application of mammalian mutagenesis to broader areas of gene function. These areas, in which ORNL has unique capabilities, represent the next grand challenge in the Human Genome Program.

4.3 • Distributed Computing at Teraflop Speeds

The use of computational tools is vital to most fields of science and engineering. These tools enable the creation of realistic models of physical situations, providing new insights into the properties of materials, the effects of human activity on the earth's climate, the structure of the human genome, and a host of other basic and applied problems whose solutions require the use of high-performance computing resources.

As computing speed and memory capacity increase, modeling capabilities improve because larger systems can be examined for longer times with fewer approximations. For example, the computer codes currently used in studying climate change are limited in spatial resolution, defined by the number of mesh points on the earth's surface, because of limits on memory. As a result, the confidence factor in the models' predictions is not as high as it would be with finer resolution. With additional memory comes the ability to decrease the distance between mesh points and thus increase the accuracy of the model. At higher processing speeds, each iteration of these calculations can be completed in less time.

Computers operating in the trillions of floating point operations per second (teraflop) range will be needed to support the next step on the very aggressive computing ladder proposed by the DOE Office of Defense Programs (DOE-DP) for its Accelerated Strategic Computing Initiative and to attain the science and engineering goals of the DOE Office of Energy Research (DOE-ER). Responses to the recent call for Grand Challenge proposals issued by the DOE-ER Office of Computational and Technology Research include several that would require at least 4 teraflops.

Achieving these capabilities will require significant developments in high-performance computing environments. Distributed computing multiplies the power available from any individual system, but it imposes a number of challenging requirements: massively parallel processing (MPP) computers; seamless access; high-speed, secure networks; data storage systems that provide ready access; and software and applications to support user needs.

ORNL and Sandia National Laboratories (SNL) propose to extend and expand their existing collaboration on distributed heterogeneous computing through the linking of two

10-teraflop systems, providing the computational power needed to carry out DOE missions in national security, science and technology, energy resources, and environmental quality.

4.3.1 • Benefits for Scientific Endeavors

Scientific investigations in a number of areas will benefit from the increased accuracy that would result from the capabilities provided by a 20-teraflop system. In addition, solutions to problems that have not even been attempted on existing hardware will become possible as speed and fast memory capability are increased. The following examples describe areas in which the availability of 20 teraflops is expected to yield significant enhancements.

4.3.1.1 • Materials Science

The social and economic impact of new materials with unique or improved properties has a long history. The material of choice may exhibit a desired property that is only a tiny improvement over another material, yet this may be enough to dominate a market and to generate sufficient income to justify sizable research expenditures. Often, in the process of incrementally improving an existing material, the discovery of a new material causes a revolution in technology.

The expected availability of computers operating in the teraflop range owes much to dramatic long-term improvements in materials and processing techniques, which have opened the door to smaller chip components and materials whose properties are dependent on nanometer-scale structures. The use of supercomputers that incorporate these improvements to carry out the accurate, atomistic modeling of materials properties is now both feasible and compelling. Proper analyses of the critically important features of materials growth, for example dendritic growth, become possible.

The availability of a 20-teraflop system could have a wide impact on many areas of condensed matter physics and materials science. In addition to manufacturing and market forces, a number of fundamental science issues demand explanations. The collective behavior of large aggregates of atoms, particularly when the behavior depends critically on temperature and microstructure (e.g., defects and interfaces), is one such question. The strength of materials, the quality of permanent magnets, and even the function of biological molecules all depend on microscopic interactions over distances larger than the scale of individual atoms and bonds. Accurate methods for evaluating the properties of large systems of atoms are needed, and the time is at hand for pursuing this goal. A number of groups are working in this general area; any breakthrough in the development of methods is sure to have an impact on many scientific disciplines.

4.3.1.2 • Global Climate Change

Modeling the earth's climate system presents a number of challenges. The development of better physical models of cloud processes and their interaction with short-wave and long-wave radiation will reduce the uncertainty in atmospheric flow calculations. The development of comprehensive, coupled ocean-atmosphere-ice climate models will be of particular importance to DOE in addressing global carbon budgets, sources, and sinks and in assessing their impacts. A further challenge is the development of prediction capability and skill for regional-scale climate changes. Each of these areas would benefit from the availability of a 20-teraflop computer system.

Current computer systems, although rated in the 100-gigaflop range, fail to deliver these peak speeds for climate simulations. The Intel Paragon XP/S 150 can sustain 5 gigaflops for the Community Climate Model, PCCM2, and 10 gigaflops for an ocean circulation model. The "best" speeds reported are from large vector processors and are in the 20-gigaflop range. If the factor of improvement for a 20-teraflop system is 66.6, then sustained performance for climate simulations of 300 gigaflops can be expected. If the percentage of the peak is improved with the 20-teraflop system, then this estimate will be conservative.

The simulation of 1 year at low resolution currently requires 2 hours on 1024 Intel i860 processors. At 300 gigaflops, such a simulation would require 110 seconds, and a 100-year simulation would take only 3 hours. Experiments with different cloud radiation models would no longer be computationally bound, and coupled ocean-atmospheric calculations would become routine and a standard part of assessment activities.

Even a 20-teraflop system, however, would not fully enable the regional climate forecasting capability. For a regional-scale skill to develop, the models must be run at significantly higher resolution. The improved resolution provided by a 20-teraflop system would nonetheless make possible simulations that are now impossible. The impact on regional climate forecasting and assessment would be to seriously start the science.

4.3.2 • Proposed Implementation

ORNL and SNL are uniquely positioned to collaborate in the linkage of two 10-teraflop systems, one to be acquired by DOE-ER and the other by DOE-DP, and the application of the resulting 20-teraflop distributed computer to scientific problems that require the full power of this system. These two institutions have

- the broadest experience with the kinds of parallel platforms needed to achieve the highest performance levels;
- experience in working together to connect large systems, developed in the current effort to link large Paragons at ORNL and SNL by way of asynchronous transfer mode (ATM) networks to solve large computational problems;
- expertise in the critically important area of forefront data storage systems, which is a key to making a teraflop-level system function effectively;
- very similar philosophies on computing and the driving role of applications; and
- strong management support at all levels to meet goals.

ORNL and SNL propose the following plan for implementing a 20-teraflop environment to support DOE-ER and DOE-DP needs and to place DOE in a leadership role in high-performance computing:

- Functional specifications and benchmark requirements established, November 1996
- Specification issued to vendors, February 1997
- Proposals received from vendors, June 1997
- Vendor selected, August 1997
- Initial system delivery, September 1998
- Completed system delivery, November 1998–February 1999

A building would be required at ORNL to house the 10-teraflop system to be acquired by DOE-ER, and ORNL is pursuing options that will provide a showcase building for this activity. Cost estimates are being developed.

Resources that are already available to support this initiative include secure networks at the Oak Ridge Y-12 Plant, which would simplify the process of bringing secure networks to ORNL so that both unclassified and classified work could be conducted on both the ORNL and SNL machines. The presence of the Tennessee Valley Authority means that the utility costs for a system of the power projected would be far lower at ORNL than at other sites.

ORNL and SNL plan to collaborate with leading universities in application areas and with other computing centers [e.g., a National Science Foundation (NSF) center and a Department of Defense (DOD) center] to enhance the laboratories' capabilities and understanding of wide-area heterogeneous computing. Both NSF and DOD have expressed interest in the existing ORNL-SNL collaboration.

This proposal provides the opportunity for cross-cutting planning to serve a broad research community (DOE-DP, DOE-ER, NSF, and DOD) and for developing a forefront capability in distributed heterogeneous computing.

4.4 • Other Initiatives

The initiatives listed below are discussed in Sects. 5 and 6. Many of these initiatives involve multidisciplinary R&D that supports more than one of DOE's business areas.

Science and Technology

- Office of Energy Research (Sect. 5.1.1)
  - National Radioactive Ion Beam Facility
  - Advanced Materials Characterization Laboratory
  - Molecular-Based Science and Engineering
  - Computational Biosciences

Energy Resources

- Office of Nuclear Energy, Science and Technology (Sect. 5.1.2)
  - Production of ^{238}Pu in HFIR/REDC

Integrated R&D Initiatives

- Integrating ORNL capabilities (Sect. 6.1.1)
  - Center for Separations and Chemical Processing
- Integrating Oak Ridge capabilities (Sect. 6.1.2)
  - Intelligent Measurement Systems Laboratory
  - Oak Ridge Energy and Environmentally Sustainable Manufacturing Center
  - Virtual Prototyping Center

5 • Scientific and Technical Programs

ORNL is engaged in basic and applied research and development (R&D) in the four business lines of the U.S. Department of Energy (DOE): science and technology, energy resources, national security, and environmental quality. Programs at ORNL frequently address multiple business lines, drawing on the Laboratory's ability to integrate its strengths across disciplinary, programmatic, and institutional boundaries. This integration supports not only DOE programs, but also work for other federal agencies and for other sponsors.

5.1 • U.S. Department of Energy

5.1.1 • Science and Technology: Office of Energy Research

The DOE Office of Energy Research (DOE-ER) is the largest single sponsor of research at ORNL. It supports programs in magnetic fusion energy (AT), high-energy and nuclear physics (KA and KB), basic energy sciences (KC), biomedical and environmental research (KP), and computational and technology research (KC05, KC07, KU). Associated activities include evaluation of energy sources (KD), laboratory infrastructure management (KG), and science education (KT).

5.1.1.1 • Magnetic Fusion—AT

The ORNL Fusion Program is distinguished by extensive collaboration, both nationally (with numerous universities, industries, and national laboratories) and internationally (with ten countries), and by the breadth of its component subprograms in physics, technology, and systems studies. Work is carried out primarily in the ORNL Fusion Energy Division, with major contributions from several other ORNL divisions, from the Engineering organization of Lockheed Martin Energy Systems, Inc., and from the Oak Ridge Y-12 Plant.

The goals of the national fusion energy research program have been recast to emphasize innovation in fusion science and technology as a central domestic theme and the pursuit of fusion energy through international partnership. ORNL supports these goals through

- theoretical and experimental studies aimed at understanding the science of fusion plasmas,
- investigation of improvements to the tokamak, as well as alternate confinement schemes,
- technology development for existing and future experiments,
- engineering design support, particularly for the International Thermonuclear Experimental Reactor (ITER), and
- the development of radiation-resistant and low-activation materials.

Support for the ORNL program comes from the DOE Office of Fusion Energy Sciences (OFES). Support for applications of fusion science and technology to areas outside fusion comes from a variety of sources both within and outside DOE.

Fusion Theory Program

The primary emphasis of the fusion theory program is on understanding plasma confinement in tokamaks, with supporting studies of alternative toroidal confinement concepts. Research focuses on the following areas:

- Analysis of anomalous transport of particles and energy. ORNL has a leadership role in the national Transport Task Force, which applies theory and experiment to gain a better understanding of transport phenomena in toroidal devices.
- Development of large-scale computational models for radio-frequency (rf) heating and noninductive current drive and of computational tools and techniques for the analysis and design of rf antennas.
- Development of models for instabilities driven by alpha particles, supporting deuterium-tritium (D-T) operations in the Tokamak Fusion Test Reactor (TFTR) at Princeton Plasma Physics Laboratory (PPPL) and preparations for ITER.
- Development of plasma simulation models and computational approaches, and application of models to specific experiments for validation and improvement of the models. This effort includes ORNL's participation in the Numerical Tokamak Project, a Grand Challenge in computational science that is being addressed by a national laboratory–university consortium.

Atomic Physics and Diagnostics Development

The Atomic Physics for Fusion Program focuses on experimental and theoretical studies of inelastic collision processes involving atomic and molecular fusion plasma impurity ions. Such data are needed to understand the behavior of plasmas in magnetically confined fusion devices and to interpret plasma diagnostics measurements. Experiments provide absolute cross sections for electron-impact excitation, ionization, and dissociation for multicharged or molecular impurity ions, and also for very low energy electron transfer between colliding heavy particles. Measurements of low-energy particle-surface interactions, an expanding part of this program, are particularly relevant to divertor designs. The experimental activity is closely coordinated with a theoretical effort, providing benchmarks for testing detailed calculations of electron-impact excitation and ionization and for fusion-relevant heavy-particle collisions.

The Controlled Fusion Atomic Data Center (CFADC) provides data on atomic and molecular processes that are relevant to fusion R&D. A bibliographic database is maintained, and recommended numerical data are available in book form and in an internationally accepted format, ALADDIN, through cooperation with the International Atomic Energy Agency. In-house data evaluation and production efforts yield important data for fusion science. Through an international consortium, the widely used Atomic Data and Analysis Structures (ADAS) suite of modeling codes and atomic data, developed by the Joint European Torus (JET) Joint Undertaking, is being made available locally. The CFADC data are now being placed on the World Wide Web (http://www-cfadc.phy.ornl.gov/). Heavy emphasis will be placed on obtaining, analyzing, and publishing data that support edge physics, divertor

modeling, and shield and limiter requirements for present and planned devices such as DIII-D and ITER.

In the diagnostics development program, far-infrared laser-based diagnostics for fusion alpha particles and electron density profiles are being developed. Requirements for application to ITER will be developed.

Spherical Tokamak Program

The Spherical Tokamak (ST) Program explores compact, low-field, ultralow-aspect-ratio plasma configurations characterized by good confinement, plasma beta levels of the order of unity, a self-driven current fraction of the order of unity, and thick outboard scrape-off layers connected to naturally formed long-channel divertors. This research may become a major component of the Alternative Concept Physics Research within the OFES Fusion Program. The following activities are planned:

- Collaborate in design, construction and experimentation for present-day ST experiments with PPPL and other institutions active in ST research. These include the National Spherical Tokamak Experiment (NSTX) at PPPL; the Small Tight Aspect Ratio Tokamak (START) at Culham, United Kingdom; GLOBUS-M at the Ioffe Institute, St. Petersburg, Russia; and the Mega-Ampere Spherical Tokamak (MAST) at Culham. These experiments are expected to prove the physics principles for ST fusion plasmas.
- Based on the expanding ST and tokamak database, study the mission and cost-effective designs for nearer-term miniature ST fusion cores, with plasma currents in the range of 6–10 MA, to test D-T burn physics and nuclear technologies.
- Study the concepts for economically competitive ST-based pilot, demonstration, and commercial power plants to guide the present research.

Confinement Program

The objective of the ORNL confinement program is to advance key scientific goals of the U.S. Fusion Energy Science Program through the application of core competencies. These core competencies are

- edge physics and particle control,
- pellet fueling,
- rf heating and current drive,
- alternate concept development, and
- theory and modeling.

The research areas are integrated in topical programs that are carried out in collaborations on facilities in the United States and other nations. International collaborations allow us to benefit from unique capabilities that are not available on U.S. machines. The topical programs are focused on concept improvement, particle transport and control, and wave-plasma interactions.

Through hardware development and active participation in experiment and theory programs, ORNL's role in the integration of physics and technology continues to expand. Efforts are concentrated in national collaborative programs on DIII-D, TFTR, and NSTX and international collaborations on Tore Supra, JET, TEXTOR, ASDEX-U, the Compact Helical System (CHS), and Wendelstein 7-AS (W7-AS). These programs focus on techniques for understanding and controlling the plasma boundary and particle transport, pellet fueling for

plasma performance and ITER scenarios, the ion cyclotron range of frequencies (ICRF) for heating and current drive, and the development of alternate confinement schemes.

Concept Improvement • The goal is to improve magnetic confinement concepts through understanding and optimization of tokamak confinement and stability and through exploration of alternate concepts. To achieve this goal, we are pursuing the understanding and optimization of magnetohydrodynamic (MHD) stability (DIII-D), investigating the sustainment of advanced tokamak plasmas (Tore Supra), exploring the effects and performance of ultralow aspect ratios (NSTX), conducting comparative transport studies in tokamaks and stellarators (W7-AS, CHS), and studying a small-aspect-ratio toroidal hybrid concept (SMARTH).

Particle Transport and Control • We study and identify the physics mechanisms responsible for particle transport in the core, scrape-off layer, and divertor; our aim is to establish a scientific basis for the effects of particle control and plasma-wall interactions on confinement. In particular, we investigate the effects of pellet fueling on density limits and the underlying mechanisms (DIII-D); study the effects of internal transport barriers on the core confinement of hydrogenic particles, helium, and impurities (DIII-D, TFTR, Tore Supra); characterize sources and transport of intrinsic impurities (DIII-D, Tore Supra); study forces on impurity ions in the divertor under different flow conditions (DIII-D); and investigate particle transport and control in stellarators (W7-AS, CHS).

Wave-Plasma Interactions • Wave-plasma interactions are studied in order to optimize heating and current drive to control pressure and current profiles for improved confinement and to develop rf heating and current drive as enabling technologies. We develop the scientific basis for the use of fast-wave current drive and mode-conversion current drive for pressure and current profile control (DIII-D, Tore Supra, TFTR), investigate synergies between long-pulse fast-wave and lower hybrid heating and current drive (Tore Supra), study the effects of edge plasma–antenna interactions and optimization for plasma performance (Tore Supra), and develop reliable enabling technologies for rf heating, current drive, and profile control (DIII-D, TFTR, Tore Supra).

RF Technology Development

ORNL is responsible for the development, design, and application of rf power on fusion experiments whose systems will provide the development basis for ITER. The long-range goal is to develop cost-effective heating and current drive systems. Extensive collaborations support the development of critical areas such as ICRF current drive, phase control, long-pulse technology and physics, advanced launchers, and advanced heating scenarios. Plans include activities in the following areas:

- ICRF current drive antenna array and phase control systems. ORNL is responsible for the design of a 32-MW system for JET. ORNL is also developing the real-time matching needed for longer-pulse or steady-state machines such as ITER.
- Long-pulse technology and physics issues. Work at ORNL has extended current drive capability to Tore Supra; this collaboration is also being used to measure how rf power modifies the edge plasma and affects antenna component lifetimes and plasma confinement. Other collaborations supporting this effort involve experiments on TFTR and DIII-D.
- Advanced launcher development and advanced heating scenarios. Waveguide antennas have much better power capability than conventional loop antennas. Using these

attributes to full advantage on large machines requires innovations such as the folded waveguide launcher and a way of removing the linkage between frequency and ion resonance. Tests at ORNL indicate that the injected power density can be extended to >20 $MW \cdot m^{-2}$ (thus reducing port size). Collaborations on TFTR, Tore Supra, and DIII-D are used to demonstrate direct electron heating techniques, which would remove the frequency link to ion resonances.

All of these collaborations support the development of advanced heating concepts and the extension of ICRF heating and current drive to other regimes.

Pellet Injector Technology Development

ORNL is a leader in developing and applying advanced plasma fueling systems for magnetic fusion. The long-range goal of this program is to develop steady-state pellet injection systems for D-T operation at moderate and high (≥3-km/s) velocities. Applications are divided among a number of facilities (e.g., tritium at Los Alamos National Laboratory's Tritium Systems Test Assembly, long-pulse operation at Tore Supra). In addition, the program provides specialized injector systems and expertise to support experimental programs. The ORNL program will concentrate on the following activities:

- Support the TFTR D-T phase with the ORNL tritium-compatible, high-speed injector.
- Develop long-pulse to steady-state, reliable pellet fueling systems for ITER.
- Develop high-speed (3- to 5-km/s) pellet fueling technology for ITER to provide innovative approaches for improved plasma operating regimes.
- Develop safe and reliable tritium pellet fueling technology for ITER.
- Upgrade the existing Tore Supra centrifuge injector for longer pulses (up to 2-min operation) to study particle control and transport in long-pulse plasmas.

Ongoing efforts in advanced technology development and applications on large tokamaks are synergistic and result in an integrated approach to the design and fabrication of innovative and reliable fueling systems for ITER and, in the long term, for fusion power plants.

International Thermonuclear Experimental Reactor

ORNL provides the ITER program with expertise in physics design (plasma performance, confinement modeling and simulations, rf heating and pellet fueling physics, plasma disruption simulations, and plasma-safety interface), design engineering, plasma technologies (pellet fueling and rf heating), fusion technologies (containment structures and robotics), fusion materials, and safety. Several ORNL scientists and engineers serve as U.S. ITER Task Area Leaders in areas such as plasma performance, rf systems, fueling, containment structures, remote handling, structural materials, and design integration. Several also serve as members of the ITER Joint Central Team, working at the Garching and Naka Joint Work Sites. Pending the U.S. decision to participate in ITER construction and operation, ORNL expects to continue in ITER program activities.

Materials Program

The Materials Program is concerned with the development of low-activation structural materials for future power-producing fusion systems and the qualification of structural materials for in-vessel components for ITER. For nonstructural applications, the program is

investigating the effects of irradiation on (1) the mechanical properties of beryllium for plasma-facing applications and (2) the electrical properties of insulating ceramics for rf heating and diagnostic applications.

Development of new materials with reduced activation characteristics, combined with the ability to carry high heat loads, is crucial to realizing the environmental attractiveness and economic potential of fusion. Three systems of materials are under development. Our work on vanadium alloys addresses the effects of irradiation, over a wide temperature range (100 to 700°C), on the mechanical behavior of V-Cr-Ti alloys and the compatibility of these materials with the various chemical environments potentially encountered in a fusion power system. In the area of reduced-activation ferritic martensitic steels, the critical issue being addressed is the radiation-induced change in fracture behavior. The third group of materials being studied, silicon carbide composites, has the potential for very high operating temperatures in thermodynamically efficient helium gas cycles. New composite materials designed specifically to resist radiation-induced degradation in mechanical behavior are being designed and developed using advanced SiC fibers and modified interfacial structures. A collaborative irradiation program with partners in the European Union, the Russian Federation, and Japan is in progress; various fission reactors are used to determine the irradiation performance of these structural materials.

Stainless steel and high-strength copper alloys are the primary structural materials for the first wall/shield, limiter, and divertor components for ITER. Our work addresses the mechanical integrity of these materials following irradiation under fission reactor conditions that encompass the ITER conditions of neutron dose and temperatures. Beryllium is a primary candidate for the plasma-facing coating of many ITER components; we are evaluating the effects of neutron irradiation on the mechanical behavior of various grades. In the area of insulating ceramics, we are quantifying the changes in electrical properties of a range of materials using in situ measurement techniques in the High Flux Isotope Reactor. These experiments are designed to simulate both the ionizing and displacive components of the ITER environment and to provide critical information on the performance lifetime of insulators for a range of applications.

International Fusion Materials Irradiation Facility

ORNL staff members are participating in an international design effort to develop a concept for an accelerator-based beam target system for the production of high-energy (14-MeV) neutrons, simulating a D-T fusion spectrum. The International Energy Agency has established an implementing agreement for the International Fusion Materials Irradiation Facility design activity, involving representatives from Japan, Euratom, the United States, and the Russian Federation. ORNL's responsibilities include leadership of the design integration efforts, definition of materials testing requirements, support for the materials test cell design, and management of the industrial consortium that provides the engineering design work for the U.S. team.

Technical and Scientific Applications

The application of fusion science and technologies to problems outside the fusion area has become an increasingly important part of Fusion Energy Division activities and now provides some 25% of the Division budget. Fusion technology has been successfully applied to waste remediation using microwaves and cryogenic pellets, improved materials production

techniques using microwaves and rf waves, plasma processing of materials, and superconductivity development and applications. This technology transfer has included work for others (funding through industry and other federal agencies), cooperative R&D agreements, and licensing of ORNL patents to industry. A goal of the Division is to expand these applications by 10% a year for the next few years.

5.1.1.2 • High-Energy Physics—KA

The High-Energy Physics Program at ORNL is focused on detector design and response data for detector collaborations, on radiation shielding design, and on the development of calculational methods that will make possible definitive high-energy transport calculations. The efforts associated with the joint high-energy physics program among ORNL, the University of Tennessee, and other Southern Association for High Energy Physics universities (in particular, Duke University, the University of Virginia, and the University of Mississippi) are expected to continue.

5.1.1.3 • Nuclear Physics—KB

The Nuclear Physics Program emphasizes basic nuclear physics research, both experimental and theoretical, and operation of two facilities: the Holifield Radioactive Ion Beam Facility, an upgrade of the former Holifield Heavy Ion Research Facility that will begin operation as a user facility in FY 1997, and the Oak Ridge Electron Linear Accelerator. Research is carried out at these two facilities by ORNL staff and by visiting scientists from around the world.

Heavy Ion Physics Task—KB02

The Heavy Ion Physics Task supports research programs in both medium-energy and relativistic heavy ion physics. These programs use accelerator facilities at several laboratories around the world.

The medium-energy research is concerned primarily with the investigation and characterization of the fundamental modes of nuclear excitation. This research program involves the study of the most collective of nuclear excitations: giant multipole resonances. In these studies the resonances are excited using medium-energy projectiles ranging in mass from protons to heavy ions. Each hadronic probe offers a unique selectivity for the excitation of various resonance modes. Of particular importance to these studies is the Coulomb excitation of giant resonances using medium-energy heavy ions. Through Coulomb excitation, both isoscalar and isovector giant resonances are excited with very large cross sections and peak-to-continuum ratios. This work also depends heavily on the measurement of the photon decay from the giant resonances using large arrays of BaF_2 detectors. New directions include studies of resonance strength in unstable nuclei, produced as beams at high-energy radioactive beam facilities, and a systematic exploration of two-phonon strength involving the giant dipole resonance. Some research effort is devoted to the study of the dynamics of collisions between complex nuclei.

At higher energies, heavy ion reactions are studied with ultrarelativistic projectiles of 200 GeV per nucleon at the Super Proton Synchrotron, located at the European Laboratory for Particle Physics (CERN) in Geneva, Switzerland. The primary purpose of this research is to study the production and characteristics of the quark-gluon plasma that may be formed in

reactions between nuclei at these energies. The quark-gluon plasma is a state of matter in which quarks and gluons, the constituents of nucleons, are deconfined over volumes of nuclear dimensions. It is believed that the entire universe existed in this state for a few instants after the "big bang" of its creation. ORNL plays a major role in the CERN-based experiments WA93 and WA98. In these experiments, emphasis is placed on measurements of photons, which—because of their nearly noninteracting properties—constitute one of the best probes of early reaction phases. ORNL has made a major contribution to the photon-detection capabilities of WA93 in the form of readout electronics.

If a quark-gluon plasma is formed at the near-threshold energies of the CERN Super Proton Synchrotron, it will be a baryon-rich plasma. In contrast, energies available at the Relativistic Heavy Ion Collider (RHIC) under construction at Brookhaven National Laboratory (BNL) are expected to lead to a relatively baryon-free plasma dominated by created particles. ORNL has a leadership role on one of the two major detectors, the Pioneering High-Energy Nuclear Interaction Experiment (PHENIX), under construction for the RHIC. This detector emphasizes measurements of electrons, muons, and photons. Because of their penetration properties, leptons, like photons, are considered to be excellent probes of the quark-gluon plasma. A certain fraction of muon and electron pairs results from the decay of vector mesons, the properties of which are likely to be a good signal of creation of dense matter and of deconfinement. ORNL participates in a number of PHENIX R&D activities, and the Deputy Spokesperson of this $70 million experiment is an ORNL staff member.

Nuclear Theory Program—KB03

The nuclear theory effort centers on basic research on low-energy nuclear structure and nuclear astrophysics and on relativistic heavy ion physics. The relativistic heavy ion program provides support and guidance for the experimental programs at CERN and BNL and entails calculations with models of hadronic evolution and hadronization. Research in nuclear structure theory takes advantage of the opportunities presented by the joint ORNL–University of Tennessee nuclear structure theory program. This program emphasizes three important themes: (1) the opportunities in traditional nuclear structure physics offered by radioactive ion beam (RIB) physics, (2) the new interface between nuclear structure physics and nuclear astrophysics afforded by RIBs, and (3) the opportunities provided by a new generation of massively parallel supercomputers for both nuclear structure and nuclear astrophysics calculations. Studies in this area include nucleosynthesis, beta decay, numerical simulations of type II supernova explosions, and nuclear reaction calculations for proton-rich nuclei. Part of the theory activities will focus on the computational Grand Challenge on the quantum structure of matter. This project is interdisciplinary in scope and involves collaborations among nuclear physicists and astrophysicists. This research will support a new level of computational nuclear structure physics and astrophysics modeling, primarily to perform algorithm development and support for massively parallel calculations.

Low-Energy Nuclear Physics Program—KB04

The major task supported by the Low-Energy Nuclear Physics Program is the new program in RIB physics, made possible by the modification of the former Holifield Heavy Ion Research Facility to produce RIBs. This project, which was completed in FY 1995, is part of a long-range plan to provide a world-class center for nuclear structure physics and nuclear astrophysics at ORNL. The upgraded facility can be considered a prototype for the

National Radioactive Ion Beam Facility proposed in the following initiative. The Low-Energy Nuclear Physics Program also supports operations and research at the Oak Ridge Electron Linear Accelerator.

Initiative

National Radioactive Ion Beam Facility

On-line isotope separator technology has progressed to the extent that it is feasible to produce and accelerate beams of isotopes that do not occur in terrestrial matter. Sufficient intensities are now available to address a myriad of nuclear structure, nuclear astrophysics, and material science issues as varied as

- delineation of the limits of nuclear stability and the evolution of nuclear shell structure, interactions, and collective modes at the limits of nuclear stability;
- production of a variety of new heavy and superheavy nuclei;
- studies of exotic transfers of nuclear matter;
- mechanisms of nucleosynthesis, stellar explosions, and galactic chemical evolution;
- new tests of fundamental symmetries; and
- tribological studies associated with deep implantation of radioactive nuclear species.

Several first-generation isotope separator on-line (ISOL) facilities, based on existing accelerators and reactors, are being constructed in North America, Europe, and Japan. For example, the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL (scheduled to start its scientific program in the autumn of 1996) will be the first such ISOL facility capable of addressing both nuclear structure and astrophysics topics.

The DOE/National Science Foundation Nuclear Science Advisory Committee has identified, in its Long Range Plan, the construction of a National ISOL Facility as the next major facility for U.S. nuclear science. This next-generation facility will provide a larger variety of more intense radioactive ion beams (RIBs) necessary to take full advantage of the scientific opportunities afforded by this new interdisciplinary research technique.

A unique opportunity exists for the construction of this facility at ORNL. With the expertise derived from construction and operation of the HRIBF, which can be considered a prototype for the National ISOL Facility, ORNL is in a leading position to compete for this $100 million facility. Likewise, the scientific program of such a facility is in line with the traditional interest of the scientific staff of the ORNL Physics Division and the users of the HRIBF.

The configuration of the planned facility is not yet fixed; a possible layout is shown in Fig. 5.1. Very intense ion beams from a $K \approx 200$ cyclotron would be used to produce radioactive atoms from fission, fusion-evaporation, and spallation reactions in a high-temperature thick target located on a high-voltage injection platform. After diffusing from the target, the radioactive atoms would be ionized, mass selected, and, if necessary, charge exchanged before acceleration to ground potential. A high-resolution isobar separator would select a single isobar for acceleration in the 25-MV tandem accelerator. After acceleration in the tandem, the radioactive ions would be boosted to their final energy by a superconducting linac. The existing 25-MV tandem accelerator and the location of the cyclotron and the target-ion source platform in existing heavily shielded areas make this configuration cost-effective.

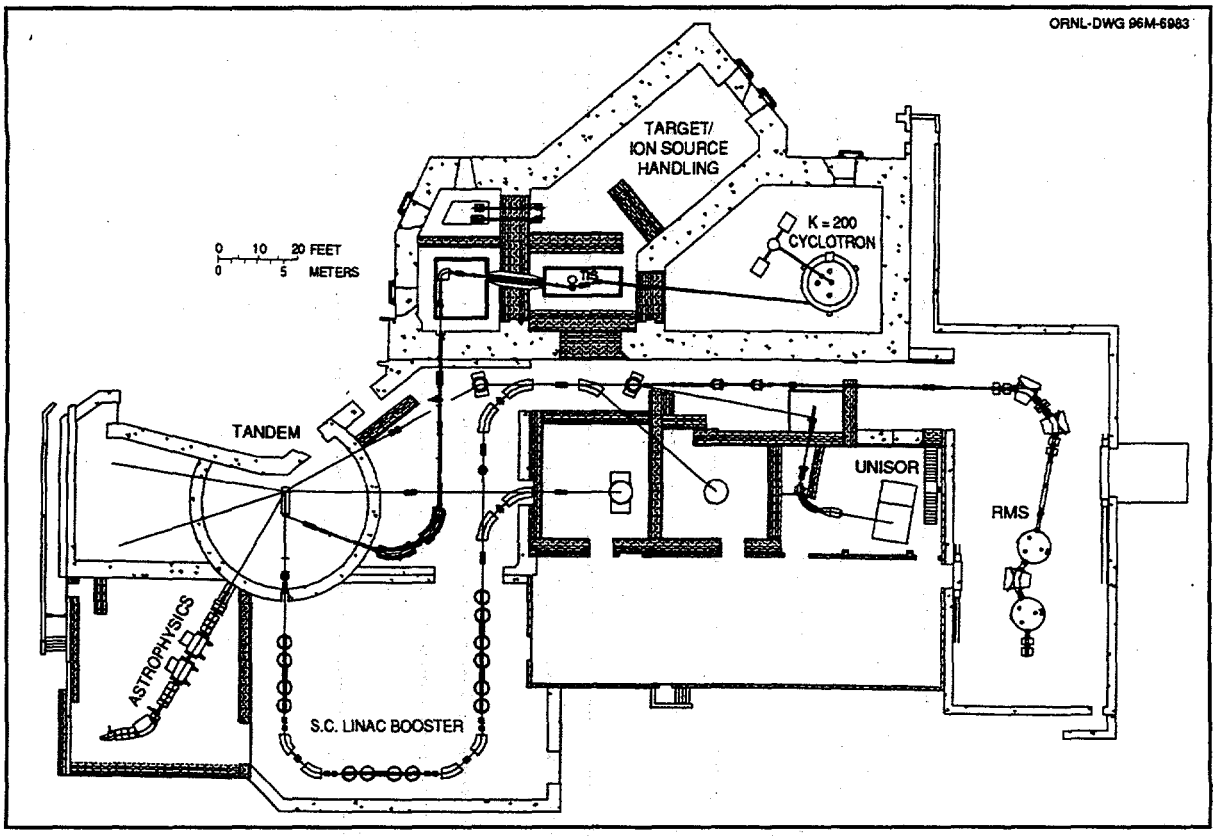


Figure 5.1
Proposed layout for the National Radioactive Ion Beam Facility in Building 6000 at ORNL.

ORNL is preparing a proposal for construction of the National ISOL Facility at the HRIBF. The proposal will be submitted to DOE when appropriate. This "second-generation" ISOL facility will be capable of providing a broad range of intense proton- and neutron-rich beams of radioactive ions to a large scientific user community. It will produce intense beams of most neutron-rich fission fragments whose half-lives are greater than about a second and which are sufficiently volatile to diffuse from a hot target. Intense beams of these isotopes are not available from "first-generation" ISOL facilities, such as HRIBF. The second-generation facility also will provide a larger variety of proton-rich RIBs than the HRIBF. Likewise, the more intense beams from the new cyclotron should provide an increased intensity for the proton-rich beams that soon will be available from HRIBF. Both proton- and neutron-rich RIBs will be accelerated from tens of kiloelectron volts for materials science studies and radioactive target preparation to above the Coulomb barrier, thereby allowing nuclei to fuse for nuclear structure studies.

Holifield Radioactive Ion Beam Facility • The accelerators of the former Holifield Heavy Ion Research Facility have been reconfigured to provide a capability for producing and accelerating RIBs. The beams from the upgraded facility, renamed the Holifield Radioactive Ion Beam Facility (HRIBF), provide a unique research capability. The combination of the Oak Ridge Isochronous Cyclotron and the 25-MV electrostatic tandem accelerator provides the capability to produce a variety of proton-rich, radioactive heavy ion

beams. Using the 25-MV electrostatic tandem accelerator (which was designed to accept low-energy, negatively charged heavy ions) as the postaccelerator for the facility allows the production of beams of heavy ions up to mass 80 for nuclear structure studies and even heavier for astrophysics. More than 100 new proton-rich compound systems can be produced using stable targets and the beams expected from the facility. Many of these systems are of special interest for studies in nuclear physics and nuclear astrophysics. The addition of neutron-rich RIBs produced from proton-induced fission is planned for FY 1998.

The HRIBF contains considerable nuclear structure research equipment from the Holifield Heavy Ion Research Facility. In addition, two new experimental stations are being constructed to fully exploit the scientific opportunities for nuclear structure and nuclear astrophysics that will be provided by the RIBs.

The new nuclear structure experiment stations comprise a recoil mass spectrometer (RMS) and arrays of detectors located both at the target position and at the focal plane of the RMS. The RMS, installed in FY 1995, will be used to isolate the rare nuclear reaction products of interest from the beam particles and other reaction products. This device, which has an unmatched capability for the study of very weakly produced isotopic species, is an excellent tool for the study of RIB-induced reactions leading to proton-rich nuclei extremely far from the stable nuclei that exist in nature. An array of high-resolution gamma-ray detectors, light charged particle detectors, and neutron detectors is being constructed around the target to detect the prompt radiation associated with the nuclear reaction. Besides detectors for determining the mass and charge of the products of a nuclear reaction, a variety of other detectors are being constructed at the RMS focal plane for measuring the radiation associated with the decay of the reaction products. Late in the decade, Gammasphere, the large national gamma-ray detector, is expected to replace the gamma-ray detectors at the target position of the nuclear structure experimental station for about a year.

A dedicated experimental station centered on the Daresbury Recoil Separator (DRS) will support direct measurements of nuclear reactions occurring in stellar explosions for the ORNL nuclear astrophysics research program. The DRS, valued at $3 million, was transferred to ORNL from the Nuclear Structure Facility at the Daresbury Laboratory in England. It is currently being installed and equipped with a new target chamber, a new segmented surface barrier detector in the target chamber, and a new microchannel plate focal plane timing detector. These detectors will supplement the two that were used with the DRS in England. Equipment planned for the DRS includes a moving tape system and associated detectors, to implant radioactive species and measure their decay, and a hydrogen and helium gas jet target to provide ultrapure target nuclei for these important astrophysics experiments.

The HRIBF Program Advisory Committee met in Oak Ridge during August 1996 and accepted 11 proposals for experiments involving both radioactive and stable ion beams. User facility operation is scheduled to begin in autumn 1996.

Nuclear Structure • The nuclear structure program on the HRIBF will extend the studies of nuclear properties to exotic nuclei not now accessible with stable beams. Studies of such less stable nuclei have a large potential for revealing new phenomena. Among the important nuclear structure issues that can be addressed with proton-rich RIBs are the limits of stability of very proton-rich nuclei, the decay of nuclei in which protons are not bound, the proton-neutron interaction, new exotic nuclear shapes, the shell closure at double-magic ^{100}Sn, tests of fundamental symmetries in self-conjugate ($N = Z$) nuclei, transfer reactions with proton-rich nuclei, and the isospin dependence of sub-barrier transfer reactions.

Late in the decade, when neutron-rich RIBs become available from the HRIBF, the new scientific topics that can be addressed will include the structure of nuclei near double-magic ^{132}Sn r-process nucleosynthesis, nuclei approaching the limits of neutron stability, and complete spectroscopy by overlapping high- and low-spin data in the same nucleus.

Nuclear Astrophysics • The nuclear astrophysics program at the HRIBF is a new effort established to use RIBs to make pioneering advances in our understanding of novas, supernovas, X-ray bursts, and other stellar explosions. The goal of the program is to determine quantitative details of these spectacular events, such as their time scales, their time-dependent temperature and density profiles, and the abundances of nuclei produced. Because astrophysical models using stable-beam studies have been unable to yield consistent qualitative descriptions of such events, our program provides an exciting and long-awaited opportunity for the nuclear astrophysics community.

The ORNL nuclear astrophysics program will be unique, since the HRIBF will be the only U.S. facility able to produce and accelerate high-intensity, low-energy, tandem-quality beams of radioactive nuclei. We will achieve our goals by measuring absolute cross sections of (p, γ) and (α, γ) reactions on proton-rich radioactive nuclei that occur in stellar explosions, exploiting the strong overlap of the required radioactive nuclear beams and the beams at the HRIBF. Measurements will be made with an experimental system centered on the DRS. This program will be integrated with stable-beam experiments and on-site theoretical efforts to fully realize the astrophysical implications of our measurements and to guide future work. In addition, it will have close ties to neutron-capture measurements made on the Oak Ridge Electron Linear Accelerator (ORELA) to understand the stellar synthesis of very heavy elements.

Oak Ridge Electron Linear Accelerator • The Low-Energy Nuclear Physics Program also supports operations and research at ORELA, a unique, intense pulsed-neutron-source accelerator facility for reaction measurements by time-of-flight neutron spectrometry. Neutron cross sections and related quantities are measured over the entire range from 0.001 eV to about 80 MeV.

The ORELA program is directed toward basic research in nuclear astrophysics and fundamental interactions. Current effort is focused on measurement and analysis of neutron capture and total cross sections for isotopic materials that are important for improved understanding of the astrophysical s-process. Measurements of other reactions important to nuclear astrophysics, including neutron-induced charged-particle reactions, are planned. The fundamental interaction program is centered on precise neutron transmission measurements designed to resolve controversy over values of the neutron charge radius and polarizability. Measurements use existing detectors, data acquisition systems, experimental equipment, and data analysis tools developed for the earlier program in nuclear data measurement for applied needs.

5.1.1.4 • Basic Energy Sciences—KC

The DOE-ER Office of Basic Energy Sciences (BES) supports a broad spectrum of research in the physical sciences at ORNL. Areas of interest include Materials Sciences (KC02), Chemical Sciences (KC03), and Engineering and Geosciences (KC04), which supports ORNL's Center for Engineering Systems Advanced Research.

Major ORNL endeavors supported by BES include the National Spallation Neutron Source (NSNS) and the High Flux Isotope Reactor (HFIR) Upgrade, which are discussed in

Sect. 4.1 as part of the Laboratory's initiative in neutron science. Other key endeavors with an impact on materials R&D include the proposed Advanced Materials Characterization Laboratory (AMCL), ORNL participation in the Partnership for a New Generation of Vehicles, and development of environmental technologies for industries of the future.

Initiative

Advanced Materials Characterization Laboratory

A 1989 National Research Council study demonstrates that materials science and engineering is one of the most rapidly developing areas of research and development (R&D)—one that is vital to the future competitiveness of the United States in the international marketplace. Cutting-edge research and close cooperation among universities, industries, and national laboratories are needed to carry ideas from inception to the marketplace in a timely manner. A plan drafted by the Office of Science and Technology Policy as a follow-on to the National Research Council study forms the basis for increased emphasis on materials R&D at a national level.

ORNL has one of the strongest and broadest materials sciences programs in the nation. In areas such as materials characterization, high-temperature intermetallics, and advanced ceramics, its successes are unparalleled. ORNL is an extremely attractive place for collaborative research with universities and industries across the United States because of resources such as the High Flux Isotope Reactor, the Shared Research Equipment Program, the Surface Modification and Characterization Research Center, and the High Temperature Materials Laboratory and because of its extensive experience in technology transfer through cooperative R&D agreements and licensing. Regional interactions have just begun to take advantage of the numerous innovative materials R&D programs that collectively span an extremely broad range of disciplines, in part because these programs are located at universities and colleges throughout the southeastern United States.

To make the ORNL materials sciences resources more useful, attractive, and available for joint cooperative projects, we previously proposed the centralization of all materials R&D taking place at ORNL. However, a cost assessment revealed that this would be prohibitively expensive. The highest near-term priority identified during the cost assessment was the centralization of advanced materials structural characterization equipment. Electron microscopes, atom probe microscopes, and nanoindenter mechanical properties equipment are now housed in buildings that barely meet the manufacturers' requirements for optimum operation of this equipment. It is clear that these buildings will not allow ORNL to maintain state-of-the-art instrumentation for the next generation of this equipment.

The Advanced Materials Characterization Laboratory (AMCL)—a new 3,000-m^2 (≈32,000-ft^2) structure that will provide the high-quality environment required to optimize performance of sophisticated characterization equipment essential for the next generation of advanced materials R&D—is proposed to meet these needs. The AMCL will foster the state-of-the-art materials characterization essential for understanding materials and materials-related processes and phenomena that underpin energy technologies and industrial endeavors.

Construction of the facility will be guided by the underlying principles of safety, environmental consciousness, and

quality engineering, integrated with the necessary environment, safety, health, and quality oversight. The total construction cost for the AMCL will not exceed $27 million. Additional cost for the initial capital equipment is estimated at $2 million. We propose that design begin in FY 1999 and that construction be completed in FY 2002.

Materials Sciences—KC02

The Materials Sciences subprogram supports fundamental materials R&D including neutron scattering; synthesis and characterization of new materials; high-temperature materials; ceramic processing; superconductivity; ion beam, laser, and plasma processing; and theoretical studies for advanced energy-related materials. This subprogram also supports four user programs that hosted 426 users in FY 1995: the Surface Modification and Characterization Research Center (SMACRC), the neutron scattering research facilities at the HFIR, and two programs co-sponsored by ORNL and the Oak Ridge Institute for Science and Education (ORISE): the ORNL-ORISE Synchrotron Organization for Advanced Research (ORSOAR) and the Shared Research Equipment (SHaRE) Program.

Metallurgy and Ceramics Program—KC02 01 • The BES Metallurgy and Ceramics Program provides the scientific leadership and fundamental framework required for the development of innovative advanced materials, processes, and characterization technologies. One strength of the ORNL program is the integration of the basic research program with the R&D efforts of DOE's applied programs, especially the materials-related efforts funded by the Office of Energy Efficiency and Renewable Energy (DOE-EE), the Office of Fossil Energy (DOE-FE), and the fusion energy sciences program in DOE-ER, as well as the Nuclear Regulatory Commission.

Important to all of the tasks are the development and application of advanced characterization techniques, including analytical electron and atom probe field ion microscopy and the mechanical properties microprobe. These capabilities are available to the general user community through the SHaRE program, supported through ORNL and ORISE. The SHaRE program is part of the Presidential Scientific Facilities Initiative. The recently acquired 200-kV analytical microscope and advanced analytical scanning microscope were accepted and are being used in SHaRE research programs and in other BES R&D efforts. Expanded atom probe capabilities are also under development. The AMCL initiative is closely related to our characterization efforts.

New research includes the application of positron spectroscopy to nondestructive evaluation of a number of materials systems and problems. In addition, a FY 1997 New Initiative Proposal is aimed at developing advanced, nondestructive analysis techniques. A 1993 New Initiative Program focuses on the study of atomistic mechanisms at interfaces with *Z*-contrast direct atomic imaging and with theoretical simulations.

Research in synthesis and processing science includes the development of fabrication and joining techniques for advanced intermetallic alloys, ceramics, and composite structures. Intermetallics research includes fundamental studies of phenomena related to physical and mechanical properties, ranging from atomic bonding to environmental embrittlement. Processing-related research includes studies of reaction sintering, neodymium magnet materials, and novel composite materials. An emerging research area is amorphous alloys. A strong first-principles theory effort is integrated with the intermetallics, magnetic materials, amorphous alloys, and related alloy design efforts. Investigations in the ceramics task are focused on establishment of basic microstructure-property relationships for the design of

advanced ceramics and ceramic composites, including silicon nitride. Under the BES Center of Excellence for Synthesis and Processing (CESP), R&D on magnet materials and toughened ceramics for gaseous corrosion protection has been strengthened. ORNL leads the CESP project on Mechanically Reliable Scales and Oxides.

The welding and joining program investigates the evolution and stability of microstructures and properties of weldments, including mathematical modeling and experimental verification of transport phenomena. This task is an active participant in the welding and joining effort in the CESP. Modeling R&D includes solidification and forming, including superplasticity and deformation process modeling. The modeling work is integrated in the CESP project on forming.

Radiation effects research, especially with regard to the effects of neutron environments, is an important part of the BES effort. This task has made major contributions to the understanding of mechanisms of reactor pressure vessel embrittlement, including a significant collaboration with the Nuclear Regulatory Commission (NRC). Investigations of radiation-induced degradation of the electrical properties of ceramics are closely tied to fusion materials programs. Work on very high gas transmutation production rates in relation to displacement damage will contribute to the success of the NSNS.

Solid State Physics—KC02 02 • The solid state physics program performs interdisciplinary research in condensed matter and materials physics to advance the understanding of materials and materials-related phenomena that underpin energy technologies. The emphasis is on fundamental problems of national scientific and technological importance in solid state theory, neutron and X-ray scattering, particle-surface interactions, thin films and interfaces, superconductivity, and the synthesis and processing of advanced materials. The program uses state-of-the-art materials research facilities at ORNL and develops advanced instrumentation and techniques for neutron scattering, synchrotron X-ray and photon research, ion beam and laser processing, and electron microscopy. Unique research facilities in neutron scattering, ion-solid interactions, and synchrotron X-ray research are made available to the scientific community through national user centers that attract more than 300 researchers each year. The program involves extensive interactions with other DOE programs, universities, government laboratories, and industry to broaden and strengthen the research and promote technology transfer.

The solid state theory program develops new theories to explain phenomena in energy-related materials and interacts closely with related experimental programs. Areas of interest include superconductivity, particle-solid interactions, surfaces and interfaces, phase transitions, neutron scattering theory, many-body theory, and magnetism. Both analytical theory and numerical simulations are performed. The program provides essential theoretical support for the experimental solid state program and involves close cooperation with the University of Tennessee (UT) through the ORNL-UT Distinguished Scientist Program and other collaborative arrangements.

The neutron scattering program uses the intense neutron beams at the HFIR to investigate the structure and dynamics of condensed matter. Current areas of emphasis include excitations and flux lattices in high-T_c superconductors, magnetic excitations in materials, the structure and thermodynamics of polymer blends, phase behavior in colloidal materials, and high-resolution residual stress measurements. Extensive improvements have been made to three neutron scattering instruments, and a significant upgrade to the powder diffractometer is under way. A new residual stress instrument is under construction as part of a cooperative program with DOE-EE (see Sect. 5.1.2.1). Completion of the spectrometer upgrades and the

new residual stress instrument will give ORNL unsurpassed capabilities in thermal neutron scattering. More than 180 researchers used neutron scattering and small-angle scattering instruments at ORNL in FY 1995.

Increased emphasis is being placed on the synthesis and processing of advanced materials. Efforts in laser ablation molecular beam epitaxy have important implications for the growth of epitaxial superconductors and compound semiconductors. Commercial interest in ORNL's thin-film lithium battery technology remains high, and new materials and composite films for related applications are being synthesized. Fundamental research on glasses and ferroelectric materials is leading to new opportunities in photonic materials. The ion implantation program continues to make progress in the use of ion beams to tailor the surface properties of materials. About 120 researchers used the ion beam facilities at the SMACRC in FY 1995, and new work on nanocrystalline and tribological thin films is under way. All of these activities involve extensive collaboration with industry, including cooperative R&D agreements (CRADAs) on photovoltaic materials, materials for thin-film batteries, thermoelectric materials, varistor materials, MgO crystal growth, plasma processing for submicron metallization, and ion beam processing (ceramic bearings, polarizing glasses, and implantation-based technologies for integrated circuits). Cooperative research is also under way with DOE-EE (SiC electronics, solid-state lithium batteries, residual stress, and superconductor development) and with DOE national security programs (materials for sensors).

Continued development and application of advanced characterization techniques are essential to the solid state physics program. In addition to the neutron scattering instrumentation upgrade described above, major new capabilities in synchrotron X-ray research, electron microscopy, and scanning tunneling microscopy are emerging. ORNL is participating in the development of the University–National Laboratory–Industry Collaborative Access Team (UNI-CAT) synchrotron beam line for the Advanced Photon Source at the Argonne National Laboratory. Support for adding a microprobe facility to UNI-CAT is being actively sought. ORNL is also a partner in the Howard University–University of Michigan–AT&T Bell Laboratories Collaborative Access Team and Complex Materials Consortium Collaborative Access Team beam lines.

The 300-kV scanning transmission electron microscope is providing unprecedented resolution for research on a wide variety of materials, interfaces, and defect structures. The surface physics program, in cooperation with the ORNL-UT Distinguished Scientist Program, is using synchrotron X rays and photons, high-energy ion beams, scanning tunneling microscopy, and traditional electron spectroscopies to investigate the fundamental properties of metal and alloy surfaces.

Superconductivity research emphasizes critical currents, thin-film superconductivity, and materials synthesis and processing. Close interactions with DOE-EE (see Sect. 5.1.2.1) and with industry are maintained through the ORNL Superconductivity Partnerships Program. This cooperation has led to a breakthrough in thin-film superconductor technology: the achievement of critical currents near the megampere per square centimeter level in yttrium–barium–copper oxide YBCO high-temperature superconductors on textured substrates.

Cooperative interactions with industry and with DOE technology programs continue to grow in all aspects of the solid state physics program. Industrial collaborations through CRADAs, the Superconductivity Partnerships Program, and the DOE Center of Excellence in Synthesis and Processing of Advanced Materials have become a significant part of the research effort. Active CRADAs number 13, and there are more than 10 cooperative programs with DOE technology programs (including DOE-EE, the DOE-ER Office of Fusion

Energy, and national security programs) and the NRC. This outreach demonstrates the technological relevance of the program and helps bridge the gap between basic science and applications.

Materials Chemistry—KC02 03 • The Materials Chemistry Program focuses modern physicochemical methods on synthesis and characterization of advanced inorganic materials and organic polymer systems.

The inorganic materials synthesis program addresses materials with high-performance optoelectronic, magnetic, and mechanical properties and emphasizes nontraditional methods of synthesis to avoid the long processing times and high temperatures of traditional solid-state synthetic chemistry. This extends the use of advanced ceramic materials to applications that were not possible previously. Sol-gel and metal organic chemical vapor deposition (MOCVD) syntheses of multicomponent oxides lower their crystallization temperatures and thus allows integration with standard silicon-based microelectronics or envisioned superconducting applications. Other synthetic techniques include spray and aerosol pyrolysis of aqueous precursor salt solutions, to produce thin films and fine-grained uniform powders, and reactive sputtering of metal alloys, to form novel nanocomposites of metals in an insulating or semiconducting matrix. A variety of characterization techniques, including atomic force microscopy and Rutherford backscattering, are used to explore structure, composition, and property relationships.

Understanding the relationships among molecular structure, processing conditions, and performance properties of modern organic polymeric materials poses a unique challenge. Experimental techniques being applied include neutron and X-ray scattering for both semicrystalline fibers and largely amorphous polymers, neutron spectroscopy, thermal analysis, solid-state nuclear magnetic resonance (NMR) spectroscopy, scanning transmission microscopy, and atomic force microscopy. Computational advances are being made in applications of molecular dynamics simulations to nanotechnology and in applications of neural networks. Used in combination, these techniques are revealing often unexpected microstructural and dynamic features, particularly in the semirigid parts of polymer systems. A theory of polymer interactions is being tested for prediction of compatibility in nanoscale polymer blends; small-angle neutron scattering is the key experimental tool in this work. This research benefits from the presence of an ORNL-UT Distinguished Scientist.

Fundamental studies are conducted on the nucleation kinetics of ultrafine oxide powder synthesis and thermodynamics of oxide superconductors. The goal of the nucleation effort is to investigate the kinetics of molecular, macromolecular, and colloidal development during the synthesis of metal oxide particles by metal alkoxide hydrolysis and to develop theoretical nucleation and growth models to predict the dynamics of particle growth and morphology evolution. The purpose of the thermodynamic research is to measure and model chemical thermodynamic data basic to synthesis and processing of complex oxides used in engineering applications. The present focus is the (Y lanthanide)-Ba-Cu-O oxides, including high-T_c superconductors.

Chemical Sciences—KC03

The Chemical Sciences Program supports the High Flux Isotope Reactor (HFIR); the Radiochemical Engineering Development Center (REDC); and a broad array of programs in atomic physics, chemical energy, separations and analysis, heavy element chemistry, and advanced battery technology.

Fundamental Interactions—KC03 01 • This program supports ORNL's experimental and theoretical atomic physics research and the operation of the EN Tandem Van de Graaff Accelerator. This program also supports two isotope production facilities, the HFIR and the REDC.

High Flux Isotope Reactor • The Research Reactors Division, part of the ORNL Advanced Materials, Physical, and Neutron Sciences Directorate, oversees the operation, maintenance, and support of THE HFIR. Programmatic funding for THE HFIR operation is primarily received from DOE-ER, and oversight is provided by the Office of Nuclear Energy, Science and Technology (DOE-NE) and the Oak Ridge Operations Office (DOE-ORO). Further information on HFIR operation is provided in Sect. 7.6.

Neutrons from the HFIR are vital to many research projects in the materials sciences, chemical sciences, magnetic fusion, and biology programs at ORNL and for users and collaborators from many universities, laboratories, and industries. the HFIR offers a unique combination of high flux, a mixed thermal/fission neutron spectrum, low irradiation temperatures, and flux tailoring. It supports neutron scattering experiments, isotope production, activation analysis, studies of material damage, and studies of advanced reactor concepts.

Use of the HFIR is expected to continue for

- neutron scattering studies for materials science,
- production of transplutonium isotopes,
- production of high-specific-activity radioisotopes (for medicine, industry, and research),
- neutron activation analysis,
- materials irradiation, and
- gas-cooled reactor fuel studies.

The major laboratory initiative in neutron science described in Sect. 4.1 includes a proposal to maintain and extend the HFIR's capabilities. In addition, continuing Departmental attention is needed to resolve long-term spent fuel storage and transportation issues.

Radiochemical Engineering Development Center • R&D activities at the REDC involve the development and use of production processes and product forms for radioisotopes, predominantly the isotopes of transuranium elements. Transuranium-element isotopes produced at the REDC are used throughout the world for basic physics and chemistry studies of the transuranium elements. They are also used in R&D programs relating to environmental effects, biological effects, biomedical applications, and waste isolation.

The DOE Transuranium Element Processing Program, the main program at the REDC, produces and distributes rare isotopes of the transuranium elements, including ^{248}Cm, ^{249}Bk, ^{249}Cf, ^{252}Cf, ^{253}Es, ^{254g}Es, ^{255}Fm, and ^{257}Fm. The process used to produce these isotopes includes (1) fabrication of curium targets in the REDC hot cells, (2) target irradiation in the HFIR, and (3) remote processing in the REDC to separate and purify each of the heavy elements and to package the individual products for shipment. Researchers—located primarily at ORNL and the Argonne, Ernest Orlando Lawrence Berkeley, Lawrence Livermore, and Los Alamos national laboratories—use the heavy transuranium elements for R&D in nuclear, organic, and solid-state chemistry; nuclear physics; nuclear medicine; and other areas. The program is sponsored by the BES Division of Chemical Sciences.

REDC activities also provide, as a co-product of the Heavy Element Research Program, ^{252}Cf neutron sources, which can be used in neutron radiography, neutron activation analysis, and cancer therapy. The ^{252}Cf Industrial Sales/Loan Program, sponsored in part by the Office of Defense Programs (DOE-DP), is carried out to fabricate these neutron sources. Source capsules are fabricated in a variety of configurations and source sizes ranging from

1 μg to 50 mg of ^{252}Cf. Nearly 240 sources are on loan for uses in medical therapy or research, teaching or demonstration at universities, and industrial applications. About two-thirds of the sources in industrial applications are used by DOE offices or integrated contractors; the remainder are used by other agencies of the federal government. Bulk ^{252}Cf is also supplied to commercial neutron source fabricators. This work is done in the REDC Californium Facility in Building 7930. Other REDC projects and capabilities include a wide variety of special radioisotope preparations and "hot" experiments in support of existing and future DOE liquid waste pretreatment and management programs.

An educational capability exists at the REDC for B.S., M.S., and Ph.D. students in the areas of radiochemistry, accelerator target development, reactor target development, integral neutron cross-section measurement, and radiochemical processing. This capability could be used to enhance the training efforts of the Glenn T. Seaborg Institute for Transactinium Sciences.

Funding for the major programs currently carried out at the REDC is ~$14 million per year. Of this amount, DOE-ER provides ~55%; DOE-DP, ~43%. The Mark 42 Processing Program sponsored by DOE-DP is described in Sect. 5.1.3.1.

Atomic Physics • The atomic physics program at ORNL comprises 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. This program currently operates the EN Tandem Van de Graaff Accelerator, which provides a wide variety of light ions and multiply charged heavy ions at energies up to several million electron volts per nucleon. Members of the atomic physics group are also collaborating on a series of atomic studies involving ultrarelativistic heavy ions at the European Laboratory for Particle Physics (CERN). At the other end of the energy spectrum, experiments on cross sections for inelastic collisions of multicharged ions with neutral atoms and molecules are carried out at the lowest attainable energies; these experiments are conducted using the ORNL electron cyclotron resonance (ECR) ion source. Studies of collisions of multicharged ions with multicharged ions have been initiated, and a new program is proposed to study details of ion-surface interactions. These studies emphasize characterizing the energy and angular distribution of ejected electrons. The ECR source provides 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 program studies atomic collisions over a wide range of energies using powerful new mathematical and computational methods. Particular attention is focused on complex systems, such as highly charged ions, that play a leading role in many branches of energy research. This program interacts strongly with the experimental atomic collision programs at ORNL and other laboratories. Many applications rely on access to super-computers, notably the CRAYs at the National Energy Research Supercomputer Center and the massively parallel Intel Paragons at the ORNL Center for Computational Sciences. Much effort has been devoted to developing algorithms that efficiently use the features of these architectures. A collaboration involving ORNL, UT, and Vanderbilt University partially supports these activities, using the Intel Paragon, which constitutes a unique resource for theoretical atomic physics. The center is interdisciplinary in scope, with components spanning atomic, nuclear, and condensed matter physics.

Molecular Processes—KC03 02 • Basic chemical research is performed to improve the fundamental understanding of methods for separating mixtures, issues

underlying analytical techniques, the physical and chemical properties of actinides, advanced battery technology, and systems related to chemical conversions that underpin new or existing concepts of energy production and storage.

Chemical Energy • A unique array of complementary experimental and modeling techniques is applied to study thermodynamics of interactions and reactions in highly nonideal aqueous solutions of electrolytes at high temperatures and pressures, especially near the critical point of water. The systems studied are selected for their fundamental significance to solution chemistry and critical phenomena and for their relevance to energy-related technologies, including steam generation, nuclear and chemical waste disposal, the extraction of heat and mineral resources, and hydrothermal geochemistry. This basic chemistry program contributes fundamental chemical information to, and interacts synergistically with, a number of co-located, more applied programs concerned with energy production, environmental quality, and waste-related R&D.

Research in surface science–based heterogeneous catalysis gives special emphasis to questions of surface structure and reactions involving multicomponent surfaces that serve as models for automotive emission control catalysts. Several ultrahigh-vacuum surface structure approaches (including low-energy ion scattering techniques developed in this program) and surface reaction approaches are employed, including synchrotron-based spectroscopies to characterize molecular adsorbates.

Obtaining new molecular-level knowledge concerning the organic chemical structure and reactivity of coals and related carbonaceous solids is an area of continuing emphasis. Structural studies highlight the application of solid-state NMR techniques to chemically modified coals, with recent emphasis on ^{19}F NMR. Reactivity studies emphasize the use of surface-immobilized compounds to simulate diffusional restrictions during thermal and catalytic processing of coal. The information derived from these basic studies will contribute to the development of novel and environmentally sound processes for the use of coal as a source of liquid fuels, chemicals, and clean energy. The unique methods developed for coal research are being extended to related issues in the thermal processing of biomass.

Studies of the photochemical reactions and associated photophysics of aromatic molecules address atypical media such as very dilute aqueous solutions and sorbent solids. In addition to elucidating basic questions of photoreactivity in anisotropic environments, this work contributes to understanding the transformation of hazardous materials in natural settings exposed to sunlight. Research on photobiochemical reactions and enzyme kinetics is related to chemical energy.

Separations and Analysis • Laser-based optical spectroscopy and mass spectrometry are major ongoing areas of emphasis in analytical chemistry research. Mass spectrometry R&D is directed at a wide range of inorganic, organic, and biological materials. Current focus areas include novel ionization methods such as electrospray, matrix-assisted laser desorption, cluster impact secondary ionization, and glow discharge ionization; ion trap mass spectrometry and gas-phase ion chemistry; precise isotope ratio measurements; biological mass spectrometry; and secondary ion imaging of both inorganic and organic targets. Basic research in laser-based optical spectroscopy places special emphasis on ultrasensitive (single-molecule) fluorescence detection, resonance ionization mass spectrometry, and nonlinear optical phenomena. This research complements a recent initiative involving microinstrumentation. Performing chemical separations and manipulations on a microchip with ultrasensitive detection is the most mature of the approaches under development. Positron spectroscopy shows promise of providing new approaches to selective ionization

and to characterizing microstructural aspects of materials. This research currently makes use of the Oak Ridge Electron Linear Accelerator. A higher-intensity positron source has been designed for a research reactor such as the HFIR.

Chemical and physical principles underlying the design of more effective multiphase separation processes are being defined. The concept of molecular recognition is being applied in the design, synthesis, and evaluation of novel ligands for separating closely related metal ions by solvent extraction. Comprehensive studies encompass organic synthesis of new ligands, crystallographic and NMR elucidation of structures of extraction complexes, and equilibrium and thermodynamic analyses of performance and speciation. Current research emphasizes selectivity based on recognition of cations, anions, and/or ion pairs. Incorporation of complexing ability, charge-neutralizing ability, and organophilicity into single multifunctional extraction agents is stressed. Synergistic program interactions occur with more applied research on environmentally relevant separation problems.

Studies of transport phenomena in the presence of external fields in multiphase systems support advanced separations processes, and fundamental investigations of the interactions of solvents, solutes, and surfaces aid understanding of supercritical extraction and adsorption. Molecular-based studies of fluids and amorphous substances are performed on massively parallel supercomputers and validated by neutron scattering. New opportunities for molecular-based engineering and science are being developed.

Initiative

Molecular-Based Engineering and Science

The combination of the computational power of the massively parallel supercomputers in the ORNL Center for Computational Sciences and the neutron scattering capabilities at the existing High Flux Isotope Reactor and the planned National Spallation Neutron Source enables a new molecular-based approach to many problems of importance in science and industry. This approach makes it possible to study various properties of materials—both naturally occurring and synthetic—at a level of detail and sophistication previously unimaginable.

With support from Laboratory Directed Research and Development funds, computational capabilities for this approach have been developed. The problems addressed are as diverse and important as the molecular-based design and development of new synthetic lubricants and new high-performance textile fibers, on the one hand, and the molecular-based understanding of corrosivity and solids deposition in supercritical water and plugging of production pipelines by waxy crude oils, on the other.

Such problems formerly required approximate, continuum models because the molecular systems involved were far too complex to be handled more fundamentally with available computational power. The advent of new molecular-based computational approaches for problems of real industrial interest heralds a revolution in many areas of engineering and science. This includes not only the traditional physical, chemical and materials sciences, but also the biological sciences, since computational approaches in biology are expected to unravel many of the mysteries underlying the behavior and function of proteins such as DNA.

For full advantage to be gained from the new computational approaches, complementary neutron scattering experiments are needed to validate the basis for the

calculations—the intermolecular potential energy functions. Because of its unique resources in computing and neutron scattering, ORNL is well positioned for leadership in this revolutionary approach to engineering and science.

This initiative, which has evolved from basic research in separations and analysis within the Chemical Sciences Program, supports many of DOE's science missions. The scope of effort is expanding beyond the Chemical Sciences and Materials Sciences programs, with proposals submitted or in preparation for a broad range of program areas within the Office of Energy Research, including Advanced Energy Projects, Applied Mathematical Sciences, and Health Effects and General Life Science. Additional proposals address the areas of industrial energy conservation for the Office of Energy Efficiency and Renewable Energy and technology development for the Office of Environmental Management.

Proposals are also being prepared for the U.S. Army Research Office and the National Science Foundation (NSF). ORNL has been asked by the CACHE Corporation, a not-for-profit corporation that promotes the use of computer-based technology in chemical engineering education, to develop a joint proposal to the NSF to encourage and facilitate the introduction of these new molecular-based techniques into the graduate and undergraduate curricula of chemical engineering departments. Interest has also been expressed by a number of potential industrial partners and sponsors, particularly from within the U.S. chemical and petroleum industries. Several industrial projects are in early stages of negotiation.

This initiative has garnered broad-based interest and support. It builds on three of ORNL's R&D competencies—computational science and advanced computing; neutron-based science and technology; and advanced materials synthesis, processing, and characterization—under the leadership of one of ORNL's Distinguished Scientists.

A Joint Institute for Molecular-Based Engineering and Science has been established by ORNL and the University of Tennessee (UT) to provide a focus for industrial, academic, and government R&D based on new molecular-level approaches. Through the joint institute, ORNL and UT will be able to leverage their complementary research capabilities, facilities, and funding opportunities.

Heavy Element Chemistry • Studies of the actinides emphasize the heaviest elements that are uniquely produced at the HFIR/REDC complex. The scientific goal is elucidation of the systematic trends in behavior of the characteristic 5f electrons as one progresses across the periodic table. Experimental approaches to define the chemical and solid-state properties of these elements and their compounds include structural studies at high pressures and temperatures; characterization of unusual oxidation states, clusters, and complexes in high-temperature vapors; absorption and luminescence spectroscopic studies of solutions and solids; and magnetic and heavy fermion behavior at low temperatures. State-of-the-art relativistic quantum mechanics calculations are carried out to complement experimental studies. New emphases highlight the relevance of this basic science to current DOE technological issues in environmental restoration and waste isolation—for example, the structural issues involved in immobilizing actinide materials in glasses. Fundamental chemical studies are also performed on actinides and fission products by exploiting photochemistry and coordination chemistry for separations purposes from molten salts, aqueous solutions, and other media.

Advanced Battery Technology • ORNL's advanced battery technology program conducts the research needed for further advancement and commercialization of thin-film

rechargeable lithium batteries developed at the Laboratory. These batteries—which are based on V_2O_5, $LiMn_2O_4$, $LiMn_xM_{2-x}$, M = Ni, Ti, Al, or $LiCoO_2$ cathodes—have many potential applications as small power supplies that can be integrated into electronic circuits at the board, chip carrier, or chip level. Several important issues addressed in this research are crucial to the commercialization of this technology: (1) exploring the structure and transport properties of the cathode-electrolyte interface, which is the major source of cell impedance, (2) conducting long-term cycle testing and investigating the origin of capacity fading in crystalline and amorphous cathodes, (3) determining cell performance as a function of temperature and discharge current density, and (4) devising methods for fabricating multicell batteries. The program also includes investigating the possible use of the lithium phosphorus oxynitride (Lipon) electrolyte discovered at ORNL as a protective coating that could improve the performance of existing rechargeable lithium–solid polymer electrolyte and lithium–liquid electrolyte batteries. Part of this research in this program is carried out under cooperative R&D agreements with several companies. Joint research is also conducted with groups at Argonne National Laboratory and with groups at several universities.

Engineering and Chemical Sciences—KC04

Engineering Research—KC04 01 • The BES Engineering Research Program sponsors two activities at ORNL: a small-scale investigation of the engineering principles governing the operation of liquid-liquid emulsion bioreactors and a second effort, the largest sponsored by the BES Engineering Research Program: the Center for Engineering Systems Advanced Research (CESAR).

CESAR's primary mission is to develop, through innovative basic research, a core of excellence in the area of intelligent systems technology. By combining long-range, future-oriented R&D efforts with near-term, sustained technology transfer to U.S. industry and with undergraduate, graduate, and post-graduate student training, CESAR strives to enhance U.S. scientific and technological capabilities in strategic areas vital to energy independence, national security, and global competitiveness. CESAR's efforts emphasize two basic research areas: cooperating autonomous systems and computational nonlinear science.

Intelligent systems are characterized as systems that integrate perception, reasoning, and action to perform tasks under circumstances that are insufficiently known in advance or that dynamically change during task execution. Perception, reasoning, and action—as well as the integration of these modules into working systems—present challenging issues for interdisciplinary basic research. CESAR continues to investigate a wide variety of these issues in the areas of cooperating agents, mobility, manipulation, intelligent multisensory systems, empirical estimation and machine learning. Specifically, CESAR's focus is on the intelligent control of mobile robots in the presence of uncertainties and constraints, and on multisensory fusion. Potential applications of interest include resource exploration; cleanup of hazardous waste; nuclear power plant decommissioning; extraplanetary exploration; search and rescue missions; security, surveillance, or reconnaissance tasks; antiterrorism missions, and industrial/household maintenance. The nature of these challenging work environments requires the robotic systems to work fully autonomously in achieving human-supplied goals. One approach to designing these autonomous systems is to develop a single robot that can accomplish particular goals in a given environment. However, the complexity of many environments or missions may require a mixture of robotic capabilities that is too extensive to design into a single robot. Additionally, time constraints may require the use of

multiple robots working simultaneously on different aspects of the mission in order to successfully accomplish the objective. In some instances, it may actually be easier or less expensive to design cooperative teams of robots to perform a mission than it would be to use a single robot. Thus, teams of possibly heterogeneous robots must be built that can work together to accomplish a mission that no individual can accomplish alone.

The objective of CESAR's research in cooperating robotics is to develop original, generally applicable methodologies facilitating the cooperation of "intelligent," heterogeneous mobile robots and to illustrate these methodologies on actual mobile robots. To accomplish this objective, several areas of cooperative systems research are addressed, including task decomposition, task allocation, achieving coherence amid distribution of control, resolution of subgoal conflicts, reasoning about activities of other agents, and inter-robot communication. In the development of cooperative robotics systems, a key challenge is to create systems that exhibit the desirable characteristics of fault tolerance, reliability, and adaptivity. A fault-tolerant cooperative system is able to detect and gracefully compensate for partial system failures, thus minimizing its vulnerability to individual robot outages. A reliable cooperative system guarantees that its mission will be solved within certain operating constraints each time it is used. Finally, an adaptable robot team is able to dynamically modify its actions as the environment or robot team changes over time.

In the area of computational nonlinear science, CESAR pursues the development of fundamental methods, including neural networks, wavelets, stochastic approximation, global optimization, and parallel processing algorithms for solving complex scientific and engineering problems in distributed systems. These systems are most often modeled by partial differential equations and involve remote sensing components. Several powerful methodologies are currently developed, based on a synergistic infusion of original mathematical, algorithmic, and engineering ideas. In particular, CESAR focuses on (1) computationally efficient neural network learning and classification algorithms; (2) powerful global optimization algorithms; and (3) optimal control techniques for solving identification problems. Applications currently under consideration are in the areas of geophysics (e.g., seismic analysis) and nonlinear time series analysis.

CESAR facilities include a state-of-the-art high-performance computing environment, as well as access to ORNL's massively parallel processors, the Intel Paragon XP/S 35 and XP/S 50 and the IBM SP-2, through the Center for Computational Sciences; numerous sensor systems, including multispectral vision sensors and laser range cameras, are also available. In order to validate CESAR's research, some resources are invested in the development of an evolving series of mobile robot prototypes. During the first phases of the CESAR R&D program, robots from the HERMIES (Hostile Environment Robotic Machine Intelligence Experiment Series) line were developed at ORNL and served as testbeds for new methods. More recently, CESAR acquired several commercial robots, including a Remotec Andros Mark VI, a TRC Labmate, a Robotics Research Arm and four Nomadic mobile robots. These have been customized at CESAR with multiple sensors (three-dimensional laser scanner, sonar, infrared, tactile, compass) and computer control. Also, new prototypes have been developed in house.

The DOE BES investment is being leveraged and enhanced by support from a number of sponsors that target applications of robotics, intelligent systems, or computational science. In particular, the DOE Advanced Computing Technology Initiative program funds basic and applied research to develop novel computational methods for three-dimensional seismic analysis. The Office of Research and Development within the DOE Office of

Nonproliferation and National Security supports applied pattern recognition and data analysis work. The DOE Office of Health and Environmental Research supports informatics and computational biology R&D that focuses on pattern recognition, database design and management, and data analysis and interpretation for genome-related applications. The DOE Office of Environmental Management's Robotics Technology Development Program has been leveraging CESAR expertise and facilities in intelligent sensor systems, sensor-based mobile robots, and software architectures for robotics applications. CESAR's expertise was also applied to the DOE-DP Technologies Enabling Agile Manufacturing (TEAM) project, focusing on virtual manufacturing for sheet metal forming. The primary non-DOE sponsor is the Department of Defense. In particular, the Office of Naval Research has initiated work in multisensor fusion with focus on hyperspectral sensors, and the Ballistic Missile Defense Organization supports research in the application of multispectral and hyperspectral imaging to subpixel target discrimination and surveillance. Other government agencies provide support for research in image exploitation for aerial surveillance and video sequence analysis.

Within its resources and environment, CESAR has been providing a focal point for cross-cutting research and development in intelligent systems and nonlinear computational science, as described in Sect. 6.1.1.2. The number of examples for successful transfer of CESAR-developed products into applied programs has been increasing as CESAR matures. The ratio of applied to basic research at CESAR has been in excess of 2:1. The ratio is higher during periods of significant involvement in projects supported by non-DOE sponsors. Recently, contacts with industrial collaborators have increased dramatically. In particular, efforts to apply CESAR expertise to new initiatives in oil exploration and recovery (*DeepLook*), robotic perception (with Ford Motor Co., using hyperspectral sensors), and advanced manufacturing are in progress. Thus, CESAR R&D activities continue to show consistent growth in the technology transfer arena.

CESAR collaborations with many national and international academic institutions are also under way. The core research program is being leveraged to provide research opportunities for minority students and faculty and to accelerate technology transfer to small businesses. For example, the Office of Naval Research, through its historically black colleges and universities (HBCU) program, provides support for a multi-institutional Center for Neural Engineering, located at Tennessee State University. The Meharry Medical School in Nashville, Tennessee, also participates in this consortium. The Center for Neural Engineering uses the special CESAR facilities in robotics and intelligent systems to provide research and training experience to faculty, graduate students, and engineers from the consortium participants.

Geosciences—KC04 03 • ORNL's geoscience research focuses on fundamental geochemical processes that control matter and energy transport in the earth's crust. The program can be divided into four general areas of research: thermodynamic properties and spectroscopic behavior of C-O-H-N fluids, mineral solubilities and aqueous speciation in low-temperature systems, stable isotope rates of exchange and equilibrium partitioning, and ion microprobe studies of diagenesis.

The pressure-volume-temperature relations of pure C-O-H-N fluids and their mixtures are determined using a unique vibrating-tube densimeter designed for operation in the range 50–4500°C and 100–2000 bar. The pressure-temperature-composition relations of aqueous C-O-H-N mixtures are studied using a hydrogen-service, internally heated pressure vessel capable of operation at high hydrogen fugacities, with an overall operating range to 10 kbar at 100–1200°C. Novel Raman spectroscopic studies of C-O-H-N fluid mixtures complement

the volumetric and phase equilibrium studies. Results from these studies are used to develop empirical and semiempirical equations of state.

The solubilities of aluminum phases such as gibbsite and boehmite and associated aqueous speciation are determined using unique high-temperature, hydrogen-electrode, potentiometric cells. This research involves the direct measure of pH of aqueous solutions over broad ranges of temperature (to 300°C), salinity, and pH in order to quantify the dissociation constants of mineral and organic acids and bases, the hydrolysis and complexation of metal ions in solution, and the solubilities and surface properties of minerals.

Stable isotope research has focused on the experimental determination of rates and equilibrium fractionations for a variety of geologically relevant systems such as C-O-H gases, liquid water–water vapor, iron oxides, and carbonates. The kinetics of carbon isotope exchange and equilibrium isotope fractionation between CO_2 and CH_4 have been determined at temperatures from 200 to 500°C. Oxygen isotope equilibrium partitioning between magnetite and water and between hematite and water has been studied at temperatures of 50–600°C and 150–350°C, respectively. Rates of isotopic exchange in two systems, carbonate-water and mica-water, have been determined at elevated temperatures (300–550°C) and pressures (1–3 kbar). Models have been developed that relate rates of exchange with the electrostatic lattice energies of minerals.

The micron-scale spatial resolution of the ion microprobe is used to quantify trace element abundances and isotope ratios of fine-grained diagenetic phases preserved in hydrocarbon-bearing sedimentary basins. Examples include a sulfur isotope investigation of sulfate reduction and sedimentary sulfide formation in hydrocarbon reservoir rocks and their relationship to hydrocarbon migration, and oxygen isotopes of diagenetic iron oxides associated with large-scale fluid migration events in and near sedimentary basins.

5.1.1.5 • Computational and Technology Research—KC05, KC07, KU

The DOE-ER Office of Computational and Technology Research provides a focal point for long-term computational and technology research. ORNL activities in these areas include the operation of a high-performance computing research center, the ORNL Center for Computational Sciences (CCS); the development of high-performance computing, communications, and information infrastructure; research in applied mathematical sciences; and participation in long-term, high-risk, industry-relevant R&D projects in critical technology areas.

The Office of Computational and Technology Research provides the direction for activities such as High Performance Computing and Communications (HPCC), the National Information Infrastructure (NII), the American Textiles Consortium (AMTEX), the Advanced Computing Technology Initiative, and the Environmental Technology Partnerships. A key current initiative of this office, with the DOE Office of Defense Programs, is the DOE 2000 program.

Advanced Energy Projects Division

The Advanced Energy Projects (AEP) Division provides support for innovative, high-risk research that does not fall under the auspices of other DOE programs. Throughout the year, ideas for research projects are reviewed by AEP staff. Following this initial screening, selected projects are reviewed at a preproposal stage; those that pass this review are considered for peer review of full proposals. Topical areas relevant to AEP cross a wide

range of disciplines, including novel biotechnology, advanced materials, chemical, and environmental research.

Mathematical, Information, and Computational Sciences Division

This division supports research in and application of mathematical, computational, computer, and communications sciences at ORNL. This includes the operation of the CCS and the conduct of basic research through the Applied Mathematical Sciences (AMS) subprogram.

Center for Computational Sciences • The CCS is one of two high-performance computing research centers established as part of DOE's contribution to the national HPCC Program. With the Intel Paragon XP/S 150, the CCS is now one of the foremost computing centers in the world. The XP/S 150 is the latest in a sequence of Intel Paragon computers that includes an XP/S 5 and an XP/S 35 (in the designation XP/S *n*, *n* represents the nominal peak speed in billions of floating point operations per second, or gigaflops). The CCS also includes a Kendall Square Research KSR1-64 machine, providing a shared memory platform. The CCS has the following responsibilities.

- Providing computing resources to Grand Challenge groups in Groundwater Transport and Remediation, Materials Simulation, Global Change [through the Computer Hardware, Advanced Mathematics, and Model Physics (CHAMMP) program, funded by the Office of Health and Environmental Research], Quantum Chromodynamics, Computational Chemistry, the Numerical Tokamak Project, and the Quantum Structure of Matter group. Support is also provided to users of the National Energy Research Supercomputer Center. The set of Grand Challenges will change in FY 1997 in response to the Mathematical, Information, and Computational Sciences Division's call for new proposals for Grand Challenge Applications. The CCS is actively participating in the proposal process.
- Providing a computing center capable of meeting program requirements, using massively parallel processing (MPP) computers and including data storage and access and networking systems consistent with the computing power of the CCS.
- Evaluating developing computer systems, procedures, and architectures.
- Developing software tools and computational techniques for high-performance parallel computing.
- Providing visualization opportunities and capabilities for CCS and ORNL users.
- Developing computationally oriented collaborative projects with industry through the Computational Center for Industrial Innovation (CCII), a DOE national user facility.
- Developing and providing advanced networking, within the computing environment and to the outside world.

R&D programs in the CCS are focused on extension of user capabilities, the Evaluation of Early Systems (EES) Project, networking, distributed computing, and software development.

Emphases in extending user capabilities include state-of-the-art data storage and access systems, the development and implementation of innovative job scheduling systems, improvement in input/output capabilities, additional computer languages, and more effective software algorithms exploiting Paragon features.

Storage and access requirements for the CCS computers are demanding and will grow with rapid increases in computing power, data file size, and sophistication with parallel systems. The CCS and the Atmospheric Radiation Measurement (ARM) Program are

developing a multiple-terabyte, high-performance file storage system that will house a complete data archive for the ARM Program (see Sect. 6.4.1.2) and meet the data archival needs of the CCS (projected at 4 terabytes in FY 1996 and increasing rapidly thereafter). The cost of the archive is shared between the ARM project and the CCS, based on the storage requirements of each. Capital requirements include systems that can effectively handle a 100-terabyte-level environment.

The National Storage Laboratory's UniTree storage system software is currently the basic system. Experiments with the next-generation High Performance Storage System (HPSS), a network-centered parallel system, are now in progress, with deployment scheduled for FY 1997. The CCS has had and continues to have a primary role in the development of HPSS, as described in Sect. 5.1.3.1.

The EES Project investigates new and experimental computer systems, focusing on innovative hardware and software features, to evaluate their suitability for Grand Challenge applications and provide feedback to machine architects, systems software designers, and application programmers. With the ORNL Computer Science and Mathematics Division, the CCS is concentrating in three areas:

- computing with emphasis on the performance and capabilities of the next generation of hardware for distributed computing;
- computing with emphasis on optimizing the effectiveness of multiple-processor-node systems; and
- networking—particularly effective highest-performance computing by linking high-performance MPP systems at separate sites with asynchronous transfer mode (ATM) performance levels.

The EES Project includes a laboratory for exploring innovations in networking that will pave the way to the gigabit-per-second region and beyond. Because first-quality networking is the key to many aspects of the computing and communications future, the importance of the availability of "operating" networks for the CCS and for Grand Challenge users throughout the nation is also emphasized.

The CCS is now working with Sandia National Laboratories (SNL) to set up a high-speed network between ORNL and SNL, with the aim of creating a heterogeneous, distributed supercomputing system made up of the largest Intel Paragons at both locations. The distributed computing initiative described in Sect. 4.3 builds on this effort. ORNL is pursuing and contemplating additional important networking experiments and strategies. The objective is the solution of massive scientific problems that cannot be solved on any currently available single platform.

Software research programs supported by the CCS include atmospheric science, materials processing, computational fluid dynamics, molecular dynamics, groundwater remediation, and engineering design. Additional research, in both algorithms and application codes, is carried out in collaboration with scientists supported through the AMS basic research program.

Grand Challenge research is supported in the CCS as part of the national HPCC Program. The groundwater modeling Grand Challenge is an extensive, multi-institution effort to develop a sophisticated flow and transport code incorporating chemical and biological phenomena. Algorithms developed through AMS basic research have greatly improved the performance of groundwater codes.

The Grand Challenge in first-principles simulation of materials properties requires the use of highly sophisticated numerical techniques and enormous computing power to provide

solutions to problems with sufficient numbers of atoms to simulate realistic conditions. During the course of this project, ORNL researchers and their colleagues at the Ames Laboratory and Brookhaven National Laboratory have developed new massively parallel order-*N* methods within the context of both tight binding molecular dynamics and multiple scattering theory and have applied them to the solution of specific materials problems. In addition, they have developed new massively parallel codes for performing ab initio pseudopotential calculations on large systems. In all cases, they have developed production codes for the CCS Intel Paragon.

The CHAMMP program (see Sect. 5.1.1.8), a DOE initiative in atmospheric and climate modeling, has achieved substantial progress and significantly higher resolution through hardware and software improvements, generated in the AMS basic research programs and in the CCS.

Industrial participation is an important component of the HPCC Program and the CCS. Intel participates in the CCS through a maintenance agreement that supports the full-time presence of five parallel systems engineers and computational scientists. Broad efforts, particularly in the ORNL Metals and Ceramics Division, have led to a wide range of cooperative projects with industry. The CCII, a national user facility, is the ORNL focal point for cooperative computational projects, with a charter that includes opportunities for extended-term, large-scale cooperative projects as well as initiation forays with organizations exploring new territory. A leading-edge visualization environment will be a key component of the CCII.

To maintain the forefront computing character expected of the CCS, ORNL staff have carefully assessed the directions of supercomputing and have made or will make the following proposals to DOE:

- In partnership with SNL, a distributed computing environment in the range of 20 teraflops, with the networking and storage systems required for this computing power, as described in Sect. 4.3. Additional partners in this initiative are the Pittsburgh Supercomputing Center and the University of California, Santa Barbara.
- An expanded staff of operating system engineers, storage experts, software developers, and networking engineers to ensure innovative design, development, and deployment of this "seamless distributed computing environment of the future."
- A coordinated and expanded effort in materials sciences that exploits the capabilities provided by the CCS/SNL project.

Applied Mathematical Sciences—KC07 • The basic AMS Program supports research in parallel processing algorithms; tools to facilitate the use of parallel and distributed computing systems; and the development of applied mathematical, statistical, and computational methods for analyses of physical processes. These research activities are supported by an Advanced Visualization Research Center that maintains state-of-the-art visualization capability for scientific research collaborations and exploring enabling technologies. The resources of the CCS are used, as appropriate, to accomplish the research objectives of the AMS Program.

Notable achievements of the AMS basic research program include state-of-the-art sparse direct solvers, iterative techniques for solving differential-algebraic equations (DAEs), and software enabling technologies for concurrent computers, including software templates. The sparse direct solvers enable large-scale linear programming problems to be solved much more efficiently. The sparse matrix codes have been adopted in sparse eigenvalue computations in large-scale modeling of structural dynamics. The DAE work enables constraints

such as conservation laws to be enforced, leading to more accurate simulations in several important applications, including the groundwater remediation Grand Challenge problem. Development and participation in enabling technologies have provided a meaningful context for mathematical software, including the creation of community standards such as BLAS, LAPACK, ScaLAPACK, PVM, and MPI. These standards are a prerequisite for the development of a concurrent software industry, which will lead to more widespread use of concurrent computers. In addition, the templates work plays a valuable role in teaching state-of-the-art numerical and parallel programming techniques to users.

Research will continue in computational techniques and tools for solving Grand Challenge problems, heterogeneous distributed computing, algorithms and software for advanced computer architectures, performance characterization and evaluation of parallel computers and programs, and mathematical modeling of environmental and engineering problems and their numerical solution on parallel computers. Specific emphasis is placed on sparse and basic matrix computations, data and information analysis, design and analysis of computational experiments, and the analysis and numerical solution of partial differential equations. Areas of increasing emphasis include high-speed communication and networking, multimedia collaboration and reports, large-scale data and information analysis and visualization, data storage, computational steering, application parallelization, electronic commerce, and information databases. Pervasive in this research are the parallel processing and related software tools to meet the computationally intensive needs of today's computer models.

ORNL is using innovative information technologies to design and implement a management environment that uses the World Wide Web. Tasks include developing generic Web-based interfaces for financial databases, defining models for project databases at DOE sites, implementing flexible security and domain restriction features, developing graphical Web-based interfaces that support multiple/matrix views, designing local intelligent software agents to support autonomous information access and analysis, identifying and incorporating searching/indexing capabilities and defining query mechanisms, and integrating all features into an initial prototype system for DOE Headquarters and DOE laboratories. This system will allow cross-cut and filtering mechanisms and capabilities that do not currently exist to integrate data from heterogeneous databases and documents distributed across the Web into precise, meaningful formats. It is crucial to bridging the gap between a browsing tool and a management tool.

ORNL's strategic plan for computing is summarized in Appendix B.

Laboratory Technology Research Division

Laboratory Technology Research Program—KU • One of ORNL's institutional competencies is R&D integration and partnerships. The Energy Research Laboratory Technology Research (ER-LTR) Program capitalizes on this strength by supporting projects that build on a mix of basic and applied research to promote substantial changes in technology areas of strategic importance to DOE's and ORNL's core missions and to American industry. Mechanisms include technology research and maturation projects and cost-shared collaborations such as cooperative R&D agreements (CRADAs), personnel exchanges, and technical assistance projects.

Within this framework, three technology research projects are being performed in three national critical technology areas: intelligent manufacturing, advanced or tailored materials, and sustainable environments. To provide a bridge between basic research and

DOE technology programs and industry, teams from the DOE-ER laboratories, universities, and industry are developing road maps and topical areas with the greatest relevance to DOE missions and industry. The goal is to promote coordinated research partnerships with specific missions.

The ER-LTR Program has three primary components: the Quick Response Program, multiyear CRADAs, and major industry partnerships such as the Aluminum Initiative, the American Textile Partnership (AMTEX), and the Partnership for a New Generation of Vehicles (PNGV). The Quick Response Program, which is block funded, includes small technology research grants, small CRADAs (<$100,000), personnel exchanges, technology maturation projects, and the technical assistance program. Management of the ER-LTR Program at ORNL is the responsibility of the Office of Science and Technology Partnerships (Partnership Office), which oversees all technology transfer activities at the Laboratory. These activities are coordinated with the Lockheed Martin Energy Research Office of Technology Transfer.

With the exception of technical assistance, projects selected for funding by this program undergo a two-step technical review by a Laboratory-wide panel of experts. The criteria for selecting research projects include enhancing and supporting ORNL core competencies and DOE public missions; pursuing high-risk research not normally funded by programmatic sources; and having a large potential benefit to industry or applied technology programs if successful. Cost-shared industry collaborations must also have substantial corporate commitment and enthusiasm with some preference given for collaborations with small business.

To maintain the high quality of the technology research projects at ORNL, each project is evaluated for technical achievements through two mechanisms: semiannual technical highlights and the annual peer-reviewed project evaluation. The semiannual technical report addresses the intermediate technical milestones or achievements of the project and provides a mechanism to evaluate the overall level of technical risk. These achievements represent benefits to ORNL and DOE, as well as to the industry partner(s).

Severe reductions (over 70% from FY 1995) in the FY 1996 budget enacted by Congress resulted in a need to stretch, cut, and terminate projects. Every effort was made to limit the impact of the reductions by taking advantage of carryover funds associated with the "off-cycle" start-up of the CRADAs. This option will not be available in FY 1997 and FY 1998, but the program projects a 10% increase in new BA for FY 1997 and FY 1998.

The ORNL portfolio now includes 38 multiyear projects (including 5 AMTEX CRADAs), 21 small CRADAs, 5 technology maturation projects, 1 personnel exchange, and 52 technical assistance projects. Nearly half of the CRADAs and over 80% of the technical assistance projects involve small U.S. businesses. Examples of the collaborative research projects and the benefits to ORNL programs and DOE missions are provided below. Additional details may be obtained from the ER-LTR Year-End Technical Report.

- A personnel exchange project with Philip Morris, with support from the Office of Energy Efficiency and Renewable Energy, has led to the development of a commercially acceptable process for melting nickel and iron aluminides. The new process, called Exo-Melt™, received a 1995 R&D 100 Award. Benefits to ORNL and DOE include the accelerated commercialization of nickel aluminides; the availability of a method for melting advanced aluminides at a 50% saving in both energy and cost; and support for fabrication of several furnace components for use at ORNL and other DOE facilities.
- ORNL researchers received a 1996 Federal Laboratory Consortium Award for Excellence in Technology Transfer for developing a new hydrogen sensor in collaboration with the

DuPont Company. The device uses thick-film compositions and is simpler, more rugged, and less costly than conventional thin-film devices. Commercial and DOE applications include the protection of personnel and equipment in confined spaces, such as reactor containment buildings. This work was supported by a technology maturation grant.

- A CRADA with Commercial Crystals has the dual goals of meeting commercial demands for large single crystals of MgO and avoiding total reliance on foreign suppliers of MgO single-crystal substrates for the manufacture of thin-film electronic devices. New insights into the formation of MgO single crystals have been obtained, leading to the formulation of a new concept for the nucleation and growth of this material and to significant improvements, resulting in the reproducible growth of MgO crystals from which substrates greater than 5 cm (2 in.) in diameter can be routinely cut, with occasional single crystals up to 7.6 cm (3 in.) in diameter. These accomplishments place this effort at the forefront of MgO crystal growth technology worldwide and provide the enabling technology for the use of this material in new and formerly impossible applications. In addition to the commercial implications of these advances, the results and capabilities are expected to contribute to many DOE-supported R&D activities, particularly in the fields of high-temperature superconductors, catalysis, and remote sensing of high-temperature processes, as well as in U.S. defense-related applications.
- A CRADA with Ohio Brass to develop a high-power electrical surge arrester material has led to the development of a material with the sharpest switching known and lower leakage current in conjunction with high nonlinearity and high voltage; lower cost ceramics processing; the first realistic model of electrical transport in arresters; improved explanations of electrical characteristics; and a better knowledge of failure modes and energy-handling limitations. Benefits include reliable electrical energy transmission that supports DOE's energy mission; better protection against nuclear electromagnetic pulses, supporting DOE defense programs; and support of materials development and theoretical modeling at ORNL through staff and data contributed by Ohio Brass.
- A small CRADA with Diffraction International has achieved an order of magnitude reduction in the cost of testing aspheric optical components. The technology for testing aspheric optics using computer-generated holograms (CGHs) as null lenses was commercialized in a novel implementation compatible with commonly available optical test equipment. The product, the CGH Null Adapter, has commercially emerged with enhancements provided through the CRADA at a price that is affordable to the smallest optics manufacturers. In addition to the technical and commercial benefits to the two partners (Diffraction International now attributes over 50% of the its revenues to the CGH Null Adapter), existing and emerging DOE and ORNL programs (e.g., in defense and manufacturing) that require precision aspheric optics now have access to the optical metrology technology and the expertise for testing them with CGHs.

The ER-LTR program is part of a broad program of outreach to industry that is described in Sect. 6.2.

5.1.1.6 • Energy Research Analyses—KD

ORNL provides support to DOE-ER in technical and economic assessments of alternative energy sources for selected sectors of the U.S. economy. Areas for peer review assessments of DOE programs include fossil energy, structural biology, and photovoltaics. The funding level varies according to the specific needs of DOE. Future technical and

analytic support for assessments will be provided as requested. ORNL anticipates providing support for analysis of global climate change issues and new analyses in support of the National Acid Precipitation Assessment Program.

5.1.1.7 • Multiprogram Energy Laboratories Facilities Support—KG

The DOE Multiprogram Energy Laboratories Facilities Support (MEL-FS) program provides funding for general-purpose, line-item construction projects at ORNL. General-purpose facilities relate to many programs and may include offices, laboratories, and shop buildings that house administrative and Laboratory-wide support functions; utility systems; and roads. Line-item construction projects are those with a total estimated cost of $2 million or more.

The MEL-FS Environment, Safety, and Health (ES&H) subprogram (KG02) has provided over $2 million in FY 1995 and FY 1996 for ES&H projects. These projects include underground storage tank regulatory compliance; decontamination of perchloric acid hoods; Occupational Safety and Health Administration (OSHA) regulatory compliance improvements for electrical, nonelectrical, machine guarding, and building grounding deficiencies; storm drain improvements; and pollution prevention projects. A large backlog of ES&H requirements has been identified and is included in the ORNL ES&H Management Plan (see Sect. 7.3). Additional KG02 funding will be applied to these requirements as it becomes available.

The MEL-FS Inactive and Surplus Facilities subprogram (KG03) provides funds for removal or minor rehabilitation of general-purpose facilities and site infrastructure with little radiological and/or chemical contamination. The MEL-FS program also supports ORNL's life cycle asset management activities, which are described in Sect. 7.5.

ORNL has a large number of facilities for which corrective construction projects are proposed. Data on site and facilities are presented in Sect. 7.5.

5.1.1.8 • Biological and Environmental Research—KP

Goals of the Biological and Environmental Research Program are to

- study the interaction of energy-related physical and chemical agents with living organisms and the environment, including their transport, chemical transformations, adverse health effects, and ultimate consequences to humans and the environment;
- map and sequence mammalian genomes;
- contribute to DOE's Nuclear Medicine Program and other beneficial applications programs; and
- transfer research findings and technological developments to the private sector.

The ORNL Biological and Environmental Research program is one of the broadest multidisciplinary life sciences research programs in the nation and covers a diverse range of basic and applied studies. These activities are described in detail in *Biological and Environmental Research Program at Oak Ridge National Laboratory,* ORNL/M-5001, Lockheed Martin Energy Research, 1996. The focus in this institutional plan is on future activities for the Office of Health and Environmental Research (OHER).

Research areas in biology include mammalian genetics, molecular genetics, protein engineering, cell biology, carcinogenesis, macromolecular structure, mutagenesis, and risk assessment. Environmental science research covers biogeochemistry, environmental biotechnology, global environmental chemistry, ecosystem studies, geosciences, hydrology, and

environmental assessment. Health sciences research encompasses human health analysis, epidemiology, health assessments, radiation and chemical physics, nuclear medicine, and instrumentation development for sensitive detection and monitoring of chemicals. Two user facilities contribute to the ORNL Biological and Environmental Research Program: the Oak Ridge National Environmental Research Park and the Bioprocessing Research and Development Center. Users of these facilities include staff members from national laboratories and industry and students and faculty members from universities. The major Laboratory initiative in functional genomics, proposed in Sect. 4.2, is an integrated activity that draws on resources from these and other ORNL programs.

During this planning cycle, this program is expected to experience growth in several areas, including global change research, protein engineering, human genome research, and basic sciences supporting environmental engineering programs and bioremediation. The ORNL Center for Biotechnology, described in Sect. 6.1.1.2, provides a coordinated focus for the Laboratory's extensive activities in bioscience and biotechnology. An initiative in computational biosciences, cutting across all elements of the ORNL program, is proposed.

Initiative

Computational Biosciences

Rapid advances in computer technology and computational sciences are having a major impact on the biological sciences. The integration of the tools of computational science into both the practice and the communication of the biological and ecological sciences is revolutionizing the understanding of the biological world. Within the next few decades, it may become possible not only to predict the three-dimensional structure of a protein from the DNA sequence of its gene, but also to make reasonable inferences about its function in the organism from which it was isolated. Sophisticated models of the local, regional, and global environments will permit more accurate predictions of the impact of human actions on the biosphere.

Computational bioscience focuses on the application of high-performance computing technology to modeling, analyzing, and displaying the underlying behavior and physical principles of biological and ecological systems. Computational areas with immediate biological impact include data access, analysis, and visualization tools; federated databases; modeling and simulation of complex systems; pattern recognition; image analysis; virtual reality; artificial intelligence; and high-performance computing facilities and software tools and environments in support of biosciences applications. Bioscience areas being affected by computational sciences include biological systems analysis and modeling (at molecular, cellular, and organism levels), structural biology, protein engineering, molecular dynamics, drug design, genome analysis, biokinetics, and environmental modeling (climate, ecosystem, population).

ORNL and DOE have a variety of resources that can be applied to computational biosciences. The technical expertise, diverse capabilities, and high-performance computing facilities at ORNL are key resources for this initiative.

An infrastructure for computational biology has been established through a Laboratory Directed Research and Development project. One focus area, the prediction of protein folds using high-performance computing tools, involves a systematic and comprehensive evaluation of existing empirical energy calculation methods based on crystallographic structures in the database,

as well as high-speed methods for evaluating potential protein folds using structural information (inverse folding) and forward folding using genetic algorithms. Both of these are being implemented on massively parallel computers such as the Intel Paragon in the ORNL Center for Computational Sciences.

New and more simplified representations of amino acid side chains have been developed, greatly improving the efficiency of energy calculations for potential protein fold evaluation. Progress in structure-based prediction of protein folds will have a significant positive impact on the Human Genome Program, on structural biology, and on computational Grand Challenges in rational protein design and drug design, catalysis, and biotechnology.

Other technical focus areas with potential long-term impact that are now being developed include interoperable analysis and database systems, an Internet server system for protein structural classification, internal biokinetic dosimetry and anatomical modeling, individual-based population modeling, and medical applications for high-performance computing. Funding is being sought from DOE's Office of Health and Environmental Research and from other sponsors. Table 5.1 provides a summary of the anticipated funding.

Table 5.1
Anticipated funding by fiscal year for the Computational Biosciences initiative
($ in millions—BA)

	1997	1998	1999	2000	2001	2002
Operating	1.0	1.2	1.8	2.0	2.0	2.0
Capital	0.2	0.2	0.2	0.2	0.2	0.2

Analytical Technology: Dosimetry Research and Measurement Science—KP01

Activities in the KP01 subprogram include development and application of cost-effective chemical and biological screening techniques, development of biological and chemical sensors for studying the effects of chemicals, application of advanced photonics (primarily lasers) for environmental needs, development and application of scanning probe microscopes for biological imaging and analysis, development of computer models for chemical and radiological biokinetics and dosimetry, application of radiation dosimetry techniques to environmental pollutant characterization, and development of biological and environmental microsensors.

The research activities of the Advanced Monitoring Technology Program are aimed at developing novel and improved monitoring technologies to measure, in subsurface environments, chemical pollutants associated with energy-related technologies. The research focus is on the development of portable instruments, cost-effective screening tools, and advanced biochemical sensing technologies for key pollutants and related biological compounds in complex samples where current techniques are unavailable or inadequate.

Dosimetry and Biokinetics • Research in dosimetry and biokinetics is aimed at establishing relationships between radiation exposure and dose by modeling the biokinetics of radionuclides in the body and the deposition of ionizing energy within radiosensitive tissues from these radionuclides and from radiation outside the body. Exposure-dose relationships compose the cornerstone of radiation protection and play an important role in the evaluation of medical diagnostic procedures that involve the use of radiopharmaceuticals

and X-ray machines. Models describing the biokinetics of radionuclides explicitly depict, as far as is practical, the tissues and physiological processes controlling the movement or retention of radionuclides in the body. These models have also been applied to chemical elements in the human body.

Instrument Development • Emphasis in instrument development is placed on providing advanced instrumentation for characterizing and sensitively detecting a wide variety of radiological species, chemical species, and related bioindicators of human exposure and health effects. Included in this effort are unique applications of laser optical techniques, ultraviolet and soft X-ray spectroscopic techniques, electron-beam microlithography, scanning probe microscopy, antibody-based biosensors, surface-enhanced Raman spectroscopy (SERS), photon-electron-rejecting alpha liquid scintillation, and mass and photoelectron spectroscopy.

New instruments and measurement techniques are developed to support evaluation of the potential health and environmental impacts of developing energy technologies. For example, cost-effective luminescence techniques for rapid screening of samples containing polynuclear aromatic compounds, as well as portable instrumentation for on-site use at operating facilities, have been developed.

Continued development of synchronous fluorescence field methods has produced faster, more cost-effective screening of organic contaminants in soil and groundwater at levels below those specified in federal regulations. Improved field concentration procedures were produced as part of these methods. Other developments include a novel method for screening polychlorinated biphenyls (PCBs) and a new luminescence technique for free cyanide in groundwater, with sub–parts-per-billion detection capability, which is being converted into a fiber-optic, in situ monitoring device for use at DOE sites. A companion method is being developed for simultaneously detecting cyanide and other important anionic contaminants based on SERS. Effort in SERS is being expanded to include monitoring of nicotine and related species in indoor air and in vivo. Follow-on funding has been received from other agencies and organizations for applied studies, with noteworthy success in technology transfer during the past 7 years.

Identification of Bio-adducts • ORNL is developing mass spectral techniques for the sensitive detection and identification of DNA adducts and other markers of molecular dosimetry, with particular emphasis on development of gas phase processes that can be used with Fourier transform mass spectrometry (FTMS) for the complete structural characterization of these important biomolecules. Two methods, matrix-assisted laser desorption/ionization (MALDI) and electrospray ionization, are being optimized for the generation of molecular ions from modified nucleic acid constituents. A time-of-flight mass spectrometer has been used to probe the fundamental nature of the MALDI process to make it more reproducible and amenable to the FTMS instrumentation. These techniques are being used to study damage to nucleic acid constituents induced by chemical or radiation exposure. In particular, polycyclic aromatic hydrocarbon oligonucleotide adducts and hydroxylated thymines (created by X-ray damage to DNA) are under investigation. This research involves extensive collaboration with biological scientists at ORNL and other federal, academic, and industrial laboratories.

Biological and Environmental Microsensor Development • The goal of this program is the development of a new class of ultraminiature and highly sensitive sensors for biological and environmental monitoring. This novel microsensor approach is based on environmental and adsorbate-induced mechanical (deflection and resonance frequency)

changes of micromachined cantilevers. The microcantilever concept, which is applicable in physical, chemical, and biological detection, is an ideal and general platform for biological and environmental sensor development. Fundamental research is expected to yield unique microscale techniques for biological and environmental monitoring and control. Extension of this concept into a universal detection paradigm for chemical sensing is being pursued.

Environmental Research—KP02

The goal of the environmental research program is to increase our understanding of the transport, transformation, and effects of energy-related activities on the environment. To gain a greater appreciation of the fundamental biological, chemical, and physical processes governing the transport and effects of materials in the environment, we emphasize linkages among the atmosphere, the terrestrial biosphere, and freshwater systems.

Natural and Accelerated Bioremediation Program • ORNL is actively involved in the initial stages of OHER's Natural and Accelerated Bioremediation (NABIR) program. With the Pacific Northwest and Ernest Orlando Lawrence Berkeley national laboratories, ORNL is supporting OHER in implementing the NABIR plan. An ORNL–University of Tennessee Distinguished Scientist is one of the science team leaders for the NABIR program and will help OHER to guide research directions while also performing active research. ORNL is also involved with an effort to develop guidelines for data quality, storage, and sharing, so that NABIR scientists will be able to collaborate effectively through the sharing of data from laboratory and field experiments.

A field-scale experiment involving the application of a genetically engineered microorganism (GEM) for the bioremediation of organic compounds is being conducted on the Oak Ridge reservation in large (800-ft^3) lysimeters, which are instrumented to monitor physiological processes and environmental conditions. The GEM strain is a *Pseudomonas fluorescens* that produces a bioluminescent response when naphthalene is bioavailable and undergoing biodegradation. The lysimeter facility is a unique ORNL resource because it is intermediate in scale between bench-top laboratory experiments and field demonstrations.

Ultraviolet B Effects • Research is being conducted to evaluate the effects of ultraviolet B (UV-B) radiation on ecosystem health, both at a genetic level and at an ecological level. Researchers are estimating and comparing the damage induced by UV-B radiation at the reproduction stage of the life cycle and at other critical stages. Components of the study focus on Ponderosa pine pollen, freshwater periphyton and grazing invertebrates, and sea urchin embryos. These organisms have been selected on the basis of their economic importance and ecological relevance; they represent terrestrial, freshwater, and marine ecosystems.

Ecosystem Function and Response • Research for OHER on ecosystem function and response in ORNL's Environmental Sciences Division focuses on the Program for Ecosystem Research (PER). This program provides fundamental insights into how ecosystems and organisms respond to environmental variations and changes, how these responses are controlled, and how they can be integrated across organizational levels. PER studies will determine the fundamental processes and properties of ecosystems that are critical to the prediction of ecosystem adjustments to perturbations such as global climate change.

The Walker Branch Watershed is a central research facility for the PER, with ongoing investigations of watershed-scale biogeochemical cycling, atmospheric deposition inputs, atmosphere/canopy interactions, biogenic emission and trace gas flux measurements, mechanisms of physiological response of vegetation to stress, nutrient cycling, subsurface

hydrologic transport, and effects of nutrient cycling processes in streams. The goals of the research conducted at the Walker Branch Watershed facility directly address the objectives of the PER by providing a mechanistic understanding of the key processes that regulate ecosystem adjustment.

Results of these process studies provide input to watershed-scale models of ecosystem response and also stimulate new hypotheses of system response that are amenable to testing. Developing a fundamental understanding of the spatial and temporal variations in processes that regulate the storage, transformation, and transport of critical ecosystem components such as carbon, nitrogen, and phosphorus is a key objective of this work. Work is progressing on a major experiment to investigate ecosystem response to long-term shifts in the moisture balance of this deciduous forest watershed. Results of this experiment will significantly expand knowledge of the potential effects of drought induced by climate change on critical ecosystem processes related to growth, nutrient cycling, and species competition. In addition to the watershed-scale research, other ongoing work in support of the PER includes studies of climate warming effects on critical belowground processes, soil carbon turnover, and implications of warming on the processes regulating forest succession.

National Environmental Research Park • The 8700-hectare (21,500-acre) Oak Ridge National Environmental Research Park is the "umbrella" organization for natural resource information and management on DOE's Oak Ridge Reservation. In addition, the park provides protected land area for long-range research planning within the framework of DOE's research park system. The park is an integral component of the Southern Appalachian Man and the Biosphere Reserve in the United Nationals Educational, Scientific, and Cultural Organization (UNESCO) biosphere reserve and the only biosphere reserve in the Ridge and Valley physiographic province. It is also a Tennessee Wildlife Resources Agency wildlife area and a designated user facility. Management of the reservation as a security buffer over the last 50 years has provided long-term habitat protection for many important species.

The park receives no direct funding from DOE. The Department's Environmental Restoration organization has funded special surveys to identify threatened and endangered wildlife and plants on the Oak Ridge Reservation. Wildlife management activities have been supported through an overhead account funded by ORNL, the Oak Ridge Y-12 Plant, and the Oak Ridge K-25 site. Wetland surveys and delineation activities have been funded through individual project requests, and educational outreach activities have been supported by ORNL, Oak Ridge Associated Universities, and other DOE programs. Data preparation on use of the park as a user facility was funded by Laboratory and ORNL Environmental Sciences Division overhead. Laboratory overhead also provided funding for involvement in the future land-use planning process to help ensure that environmental preservation and research concerns will be addressed in the process. In addition, DOE's ParkNet system provided a networking mechanism for communication in the preparation of a proposal for the multiagency Strategic Environmental Research and Development Program (SERDP).

Maintaining biodiversity and providing sites for research and demonstration projects are the focus of natural resource management. These management goals support various partnerships with state and regional agencies. Wildlife management is done cooperatively with Tennessee Wildlife Resources Agency. The Nature Conservancy has prepared a preliminary report on the biodiversity of the reservation. There are six registered State Natural Areas through interaction with Tennessee Department of Environment and Conservation. Funding for an ecosystem-based management plan for the ORR would be used to (1) expand on these partnerships for planning, implementation, monitoring, and demonstration of

sustainable, adaptive management and (2) continue to provide a strong foundation for ecological research of national interest.

Park-related information is provided to DOE and to the public (see Sect. 6.4.2). Park personnel have conducted wildflower hikes, bird walks, and public field tours of the Oak Ridge reservation for viewing of the population of tall larkspur (a Tennessee-listed rare plant). They have also made public presentations about the reservation as a valuable natural resource. Data were also provided for the Nature Conservancy evaluation of biodiversity as part of the DOE future-use initiative.

Theoretical Ecology • Research in theoretical ecology will focus on global change and other DOE needs and the theory to integrate biological processes (e.g., biodiversity and structural organization of ecosystems) across different scales. The development of spatially explicit decision models for land management funded by SERDP will be used to assess the impact of DOE activities on natural and cultural resources. The research will build on and require further development of ORNL's expertise in the theory of risk assessment, spatial analysis, and dealing with information at different spatial and temporal scales. Theoretical approaches that are being explored will extend the results of experimental studies being performed as part of the PER to broader spatial and temporal scales and to a wider variety of conditions.

Subsurface Science Program • The DOE Subsurface Science Program (SSP) emphasizes the integration of microbiology, geology, hydrology, and geochemistry to understand natural processes that control element mobility in the subsurface. Increasing our knowledge in this area will lead to an improved ability to characterize, monitor, and treat DOE sites contaminated with radionuclides, organics, and metals.

ORNL staff perform research in support of several portions of the SSP. Extensive research has been conducted on the transport and transformations of cobalt–ethylene diamine triacetic acid (EDTA) complexes in heterogeneous subsurface systems. Current efforts include quantifying the role of microbial reactions coupled to the inorganic reactions. This work will lead to an understanding that will directly benefit DOE sites where ^{60}Co contamination is prevalent.

Investigations of microbial heterogeneity are being conducted at field locations in the eastern United States to determine the parameters that control the distribution of microbial populations in the subsurface. This work has significant implications for understanding the evolution of natural microbial populations in the subsurface and for determining how native microbial communities might be used for in situ bioremediation. Understanding the heterogeneity is critical to evaluating whether these communities can be effective in contaminated areas.

Other SSP investigators are conducting related investigations of bacterial transport in the subsurface. Through these investigations, bacteria with capabilities to perform novel remediation or manufacturing processes may be developed.

Research is being conducted to understand how colloids may be generated in the subsurface, both naturally and under stressed conditions that may be found during in situ remediation. Colloids can be used to both mobilize and immobilize contaminants. Therefore, understanding the processes that control the formation and transport of colloids and any attached contaminants is critical in assessing the risk that may be present at a site before, during, and after treatment.

Environmental Management R&D—Basic Science • Work is under way to address the following broad objectives, which are interrelated and of significant priority in the following order:

- implementing a consistent approach in assessing (1) the impact of remediation on human and environmental health and (2) the health and environmental risks associated with historical, current, and planned waste management and disposal operations;
- gaining an understanding of the hydrogeological, biological, and geochemical factors that control the movement and chemical transformations of radioactive, hazardous, and mixed wastes in soils and in subsurface and surface water systems;
- developing methods for accurately predicting contaminant movement in the environment;
- developing new remediation technologies (physical, chemical, and biological) for environmental restoration; and
- using methodologies in performance assessments and postremediation monitoring.

These broad objectives demand the integration of a variety of technical disciplines. Analysis capabilities, including those related to geochemistry and hydrology as well as to risk analysis, must be developed, and fundamental databases are needed to support the analytical models. The relationships between wastes of different types and a variety of natural processes must be studied. We emphasize microbial transformations that can be used in remediation and other biological parameters that can serve as indicators for risk and performance assessment. This work will require enhanced robotics and computational capability and the use of decision analysis methods that incorporate risks, costs, and benefits as a means for aiding restoration decisions. Basic research issues of importance to the waste R&D effort will change as technologies develop and as new problems are encountered.

The Environmental Management Science Program (EMSP) is a new, collaborative initiative administered in partnership by DOE-ER and the Office of Environmental Management (see Sect. 5.1.4.1). It is designed to identify and fund basic science research in the areas critical to the cleanup and restoration of the Department's contaminated sites. In FY 1997, ORNL will begin work on 11 projects funded by the EMSP. These projects were selected through a competitive process from more than 810 proposals made by DOE national laboratories, other federal laboratories, industry, and academia.

Health Effects and General Life Sciences—KP03, KP04

Common themes within these activities are interactions of animals, cells, and molecules with their environments. The physical properties of materials of biological or environmental importance, mechanisms that govern transport and chemical transformations of pollutants, and the details of direct interactions of harmful agents with biological materials are studied both theoretically and experimentally. Efforts encompass interactions at the atomic, molecular, and macroscopic levels in solids, liquids, and gases; on surfaces; and at solid-liquid interfaces. Strong emphasis is also placed on developing techniques that provide advanced instrumentation for characterizing and sensitively detecting a wide range of chemical species and related biomarkers of health effects. Included in this effort are unique applications of laser optical techniques, ultraviolet and soft X-ray spectroscopic techniques, electron-beam microlithography, electron microscopy, scanning tunneling microscopy, mass spectrometry, and picosecond laser techniques. ORNL's program for experimental studies of picosecond processes in liquids, gases, and molecular clusters concentrates on studies of structure and dynamics relevant to energy deposition. Programmatic areas of emphasis in

health and general life sciences also include mammalian genetics, protein engineering, and molecular and cellular biology.

Mammalian Genetics • A large mouse colony and staff expertise in genetics, molecular biology, cytogenetics, pathology, reproduction, and development provide the resources for coordinated studies that use mutations of all kinds to investigate genome structure/function correlations, mechanisms of mutagenesis, and the action of genes in development. Hundreds of mutations induced by radiation and chemicals include valuable complexes of overlapping deletions and other rearrangements. Insertional mutagenesis (by transgenic mouse technology) provides molecular tags for access to and cloning of genes, and targeted mutagenesis (by embryonic stem-cell technology) enhances the means for exploring gene function.

Molecular and advanced cytogenetic techniques are used for analyzing the nature of agent-induced and insertional mutations, advancing the understanding of mechanisms of mutagenesis. In addition, the program is a national resource for studying genetic risk from environmental mutagens and for determining the sensitivities and biological properties of diverse types of reproductive cells.

The mouse genetics colony, which propagates stocks of hundreds of mutants that have arisen over decades of mutagenesis studies, is an international resource that is exploited through both outreach and in-house research; it is increasingly important for attempts to understand gene function. Mutant stocks are supplied to laboratories throughout the world for collaborative or independent investigations. Furthermore, the numerous mutations centered on each of seven specific loci have been characterized into deletion complexes that constitute invaluable resources for intensive regional genome mapping.

The mouse genome is analyzed with the objectives of building bridges to the human genome and especially of finding functions for human genes that might otherwise be characterized only at the structural level. Detailed maps of selected regions of mouse-human homology are being developed, and the comparative maps are being refined by assigning human complementary DNA (cDNA) clones to positions on mouse chromosomes. Because neither mutation induction nor certain developmental studies are feasible in humans, the mouse provides an excellent model for exploring the in vivo functions of human genes. The pathology and developmental physiology of selected mouse mutants that provide models for human genetic disorders are investigated in depth. Examples are DNA-structure/function studies in stocks propagating mutations that cause congenital cleft palate, polycystic kidney disease, and an autoimmune disorder.

Cryopreservation of embryos and sperm is essential to the maintenance of the accelerating numbers of transgenic and other mutant lines. Consequently, with strong encouragement from OHER, ORNL is investigating the fundamental factors that will permit the development of cryopreservation procedures for mouse sperm.

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

In its breadth and integration of many activities in molecular genetics and biochemistry, ORNL's program in protein engineering is unique among DOE laboratories. Long-term

efforts are focused on enzymes that are relevant to biomass yields and on polypeptide hormones that regulate cellular growth and differentiation.

Related studies in the area of macromolecular structure–function include X-ray crystallography of nucleosomes (core particles of chromatin) and enzymology of eukaryotic messenger RNA turnover, inclusive of relevance to cellular growth and differentiation.

Given the relevance of protein engineering to multiple missions of DOE and the proven track record of this program, expansion would be warranted if permitted by budgets.

ORNL Genome Program • ORNL is strongly committed to active participation in the national effort to analyze the human genome and to moving to the next step in this effort, the determination of gene function, as described in Sect. 4.2.

Comparisons of structure and function within related regions of the mouse and human genomes and development of advanced sequencing and mapping techniques are two thrusts of the ORNL program. The mouse provides an excellent model system for exploring in vivo functions of human genes for a number of reasons: extensive homologies exist between the genomes of humans and mice; genetic engineering procedures coupled with standard mutagenesis tools are available for experimentally manipulating the genome of a mouse; and many experimental studies that are not feasible in humans can be done in mice. Most important, mutations generated in mice provide powerful tools for the correlation of genome structure with function and will prove to be crucial in deciphering the biological information inherent in the emerging physical maps of the human genome.

OHER has funded a multiple-investigator project on mouse-human genome relationships that is proceeding as follows.

- The existing mouse-human comparative genetic map is being refined and expanded by assigning conserved human DNA markers, primarily cDNA clones, derived from specifically targeted human regions to corresponding regions of the mouse genome.
- Through use of physical mapping and cloning techniques, detailed comparative physical maps are also being developed within selected regions of mouse-human genomic homology, in collaboration with the Human Genome Center at Lawrence Livermore National Laboratory (LLNL).
- For integration of mouse-human comparative mapping data with existing genetic maps of mouse mutations and clone maps generated by other research groups, selected, well-spaced simple sequence repeat markers are also being assigned to ORNL's cDNA-based map.
- The ready availability of tissues and RNA samples from every stage of mouse embryonic and adult development is being exploited to provide in-depth "surrogate" expression profiles for conserved, known, and anonymous human genes.
- To examine genomic relationships in further detail, and to provide new tools to aid in the analysis of human sequencing data, ORNL, the LLNL Human Genome Center, and other groups are working to determine the DNA sequence of parallel segments of related mouse and human DNA.
- To facilitate the integration of mouse and human mapping, gene expression, and sequencing data, ORNL and LLNL teams are working to construct a comparative mapping database to be shared by the closely collaborating groups.
- To provide ready links between cloned human genes and health-related phenotypes, map positions of a large number of mouse mutations, caused by reciprocal translocations, and conserved human cDNAs are being correlated through the use of the mouse-human comparative map.

Carbon Dioxide Research—KP05

ORNL is a center of expertise in global environmental research. Activities include developing global biogeochemical models, implementing data and information systems, integrating social systems with science and technology, fostering the application of high-performance computing to atmospheric general circulation models (GCMs), conducting field and laboratory research on the effects of CO_2 on vegetation, and conducting integrated assessments of the consequences of global change. ORNL is also exploring appropriate science and technology needed to support sustainable development activities domestically and internationally. These activities and other research thrusts within other existing ORNL programs are the technical foundation for the ORNL Center for Global Environmental Studies (see Sect. 6.1.1.2), which involves staff members from many ORNL divisions as well as outside collaborators.

The Carbon Dioxide Information Analysis Center (CDIAC) compiles, evaluates, and distributes information on CO_2, other greenhouse gases, and long-term climate changes, in support of the CO_2 research program. In the coming years, the Center's research activities will focus on the areas of emphasis of DOE's Global Change Research Program (e.g., carbon emissions from fossil fuel combustion; carbon fluxes between the atmosphere, the oceans, and the terrestrial biosphere; long-term climate records). CDIAC will also focus on electronic distribution of its data and information products and on fully integrating its data management activities with the U.S. Global Change Data and Information System. CDIAC's scientific and technical information management activities are described in Sect. 6.4.1.2.

Computer Hardware, Advanced Mathematics, and Model Physics • The Computer Hardware, Advanced Mathematics, and Model Physics (CHAMMP) program is directed toward the development of an advanced climate model that uses the hardware and software capabilities of massively parallel processing (MPP) computers and incorporates the best numerical approaches for atmospheric and oceanic dynamics, combined with the most accurate representation of cloud feedbacks, chemical processes, and terrestrial systems. In the near term, CHAMMP will achieve improved GCM performance by using MPP supercomputers such as those in ORNL's Center for Computational Sciences (CCS). ORNL scientists are working with staff members from Argonne National Laboratory and the National Center for Atmospheric Research to provide parallel implementations of the Community Climate Model and improve key numerical algorithms for parallel computation. ORNL scientists are keenly interested in CHAMMP projects that will couple atmospheric, oceanic, and terrestrial models. With these models, new understanding of the CO_2 problem may be gained.

Carbon Dioxide Effects • In support of the DOE Terrestrial Carbon Program, researchers are investigating the potential for elevated concentrations of atmospheric CO_2 to ameliorate the adverse effects of climate warming on forest tree species. Tree seedlings are being grown in multiple temperature-controlled, open-top chambers in the Oak Ridge National Environmental Research Park. The effects of CO_2-temperature interactions on tree growth are being measured to explore the mechanisms of plant and ecosystem adjustment. A particular objective of this research is to describe the direct and secondary processes involved in carbon cycling and sequestration by forests. This research will lead to a more realistic assessment of the integrated responses of terrestrial ecosystems to global change.

Atmospheric Radiation Measurement • The Atmospheric Radiation Measurement (ARM) Program is a DOE initiative to aggressively monitor atmospheric phenomena that affect heat flux, with the objective of providing an experimental testbed for studying the effects of atmospheric phenomena, particularly cloud interactions, on long-wave radiative

processes. This information will be used to improve the modeling of atmospheric and radiative processes, with the ultimate goal of improving GCMs. ORNL serves as the data center for all data generated by this program. Staff in the ORNL Environmental Sciences Division are developing the ARM archive facility to provide scientific data management for the project data, with support from the CCS. Also under development are methods to document and summarize the data and to provide user access tools. Documenting and summarizing the ARM data will be particularly critical because the ARM archive will be the primary point of contact for the general scientific community seeking data from the project. The ARM archive activity is described in more detail in Sect. 6.4.1.2.

Socioeconomic Studies • The objective of ORNL's socioeconomic studies is to lay the economic foundations for more complete and realistic integrated assessment models. At a more fundamental level, socioeconomic research activities provide a better understanding of the processes by which the economy may move to new technologies that address climate change.

Current research efforts are aimed at incorporating more sophisticated and complete economic components into integrated models to address global climate change. Research is focusing on economic productivity and the role of technological advances that would affect the level of uncontrolled greenhouse gas emission, the ability to mitigate emissions, and the ability to adapt to potential changes in climate. Evolutionary modeling methods are being applied to the problem of characterizing long-run technological change and technology adoption in energy-economic systems. Traditional approaches have been limited by their evaluation of long-term change and technology choice. Experimental economics is being used to evaluate different investment models, such as the irreversible investment approach, which suggests that when there is uncertainty, irretrievable sunk costs, and the ability to wait while gathering more information, investors will require premiums akin to option values before investing.

Integrated Assessment • Integrated assessment is a process in which the scientific, technical, social, environmental, and economic inputs into and consequences of a decision are evaluated to provide the information and analyses needed by policy makers and other decision makers to arrive at informed decisions on science and technology. For any problem, integrated assessment identifies the policy alternatives; analyzes the scientific, technical, social, environmental, and economic costs and benefits of each alternative; identifies the major sources of uncertainty; and provides some measure of the consequences of a wrong decision. As described in Sect. 6.1.1.3, ORNL has a unique breadth of scientific, engineering, environmental, economic, and social science expertise to address the broad range of issues that arise in performing an integrated assessment, as well as extensive experience in using interdisciplinary teams to address a wide range of issues, from the generic relicensing of all commercial nuclear power plants in the United States to evaluating the safety, environmental, and health initiatives supporting U.S. research operations in Antarctica.

Medical Applications—KP06

Nuclear Medicine • The ORNL Nuclear Medicine Program focuses on the design and development of new tissue-specific radiopharmaceuticals for diagnostic and therapeutic applications in nuclear medicine. Key strengths of the program are radiopharmaceutical chemistry, animal evaluation, radiochemistry, development of radioisotope processing techniques, and radionuclide generator research. The High Flux Isotope Reactor (HFIR)

represents an important resource for this program, and the development of radionuclide processing technology and generator research are major areas of productive work.

The molecular modeling of new tissue-specific radiopharmaceuticals is a major emphasis. The development of ^{123}I- and ^{18}F-labeled cerebral receptor binding agents is a key example. Certain molecular forms can measure changes in neurotransmission encountered in many neurological diseases. The goal is to measure, by means of external imaging techniques, changes in receptor density or activity that occur in various diseases. Agents under development include improved analogs that bind to the cholinergic-muscarinic receptors involved in dementias such as Alzheimer's disease and new analogs that bind to the serotonergic receptors that are involved in mood disorders.

In conjunction with the syntheses of these and other agents, new and improved radiolabeling techniques are being developed for radioiodination of molecules sensitive to the usual methods. For example, ORNL has developed a ^{188}W/^{188}Re generator system, which provides carrier-free ^{188}Re as either perrhenate or perrhenic acid for radiolabeling various therapeutic agents. Large, clinical-scale generators have been developed, a clinical prototype has been patented, a cooperative R&D agreement (CRADA) has been established with RhoMed, Inc., in Albuquerque, New Mexico, for evaluation of new ^{188}Re-labeled agents for cancer therapy, and the generator system has been licensed to Isotope Product Laboratories, Inc., Burbank, California, for regulatory approval and commercialization. Optimization of the reactor preparation and processing of a variety of other radioisotopes of biomedical interest is also in progress.

A variety of ORNL agents are being evaluated in both preclinical and clinical studies, with more than 20 medical cooperative programs at university hospitals and research institutions in the United States, Europe, Asia, and Australia. These programs represent an effective mechanism for further evaluation of agents developed through collaboration with programs featuring special expertise in cardiology, oncology, and neurology. ORNL-developed agents include the ^{188}Re-labeled antibodies for cancer therapy; multiple-center trials have been initiated with ^{188}Re phosphonates for treatment of bone pain from cancer and new ^{123}I ligands for brain and heart imaging.

T-cells infected with the human immunodeficiency virus (HIV), which causes acquired immunodeficiency syndrome (AIDS), take up azidothymidine (AZT, similar to thymidine, a component of DNA) in much larger quantities than do uninfected T-cells. ORNL researchers, working with Children's Hospital in Boston, exploited this property in developing a strategy to kill cells infected with HIV. The radioisotope ^{195m}Pt, which is highly radiotoxic when confined to a living cell or when the dead cell is engulfed by a macrophage, was attached to the AZT molecule. The use of radiolabeled AZT to destroy infected T-cells and macrophages could lead to more effective treatment of AIDS.

Research in this program continues to receive international recognition, and a variety of invention disclosures, patents, and licenses have been consummated. The balance between basic R&D at ORNL and interaction with other institutions forms the basis for the continued strength of this program. Research efforts will continue to be expanded in the area of molecular nuclear medicine.

Molecular Immunology • Some of the proteins on the surface of cells are tissue-specific and may be altered in kind and amount in the carcinogenic process. ORNL researchers have developed monoclonal antibodies (MAbs) that recognize epitopes on a glycoprotein (thrombomodulin) that is expressed exclusively by lung vascular endothelial cells. This glycoprotein target provides opportunities for the use of MAbs for imaging both

vasculature and tumors. This model system is being used to generate preclinical data on the efficacy of tumor vasculature targeting. An alpha-emitting isotope (^{213}Bi) is delivered to tumor vasculature for therapy of perivascular tumors. These studies are in parallel with use of this isotope at the Memorial Sloan-Kettering Cancer Center to treat lymphoid cancers. Liposomes can be targeted with these MAbs, with the possibility of targeting chemotherapeutic agents. They may also be used to deliver specific genes to cells for genetic-based therapy.

Other research focuses on the interactions of tumor cells with host vascular endothelial cells, which lead to either neovascularization or metastases. Several adhesion molecules, growth factor/receptor combinations, and proteases have been implicated in these interactions. New MAbs that react with tumor blood vessel cells of the rat are being studied. Target molecules include flt-1, the receptor for vascular endothelial cell growth factor, and the vitronectin receptor, an integrin molecule implicated in neovascularization of tumors. Antigens expressed on tumor endothelial cells provide excellent targets for MAb-directed delivery of short-lived radioisotopes. The efficacy of this approach in inhibiting angiogenesis and tumor growth will be evaluated in rat model tumor systems. Some of the MAbs developed in this work are now being distributed commercially.

5.1.1.9 • University and Science Education—KT

The ORNL-obligated portion of DOE's University and Science Education Program supports the administration and conduct of mathematics and science education activities at all academic levels. These activities are coordinated through the ORNL Office of University and Science Education.

ORNL works closely with the Oak Ridge Institute for Science and Education and with Associated Western Universities in administering both summer and academic-year research participation programs. More than 35 programs (see Table A.3 in Appendix A) enable students and teachers to enrich their learning experience or advance their professional development through interactions with ORNL staff and access to ORNL facilities.

In addition to faculty and student programs, the focus of ORNL's education programs includes local, state, regional, and national systemic reform initiatives; public science literacy; and educational technology. Education activities as an integral part of the Laboratory's science and technology partnerships are described in Sect. 6.2.4.

In response to reduced funding, options have been developed for partial support of some precollege science education programs through financial participation by external partners on a fee-for-service basis. Other creative approaches to funding are being explored.

5.1.2 • Energy Resources

5.1.2.1 • Office of Energy Efficiency and Renewable Energy

ORNL works on a wide range of programs for the Office of Energy Efficiency and Renewable Energy (DOE-EE). The mission of the ORNL Energy Efficiency and Renewable Energy Program is to assist DOE-EE in accelerating the development and deployment of sustainable energy technologies, thereby creating a cleaner environment, a stronger economy, and a more secure future. The program employs an integrated approach to achieve this mission: it combines applied research with technology development and deployment activities; it draws on the expertise of multidisciplinary teams capable of tackling large, complex

problems; and it involves a wide array of industrial, academic, and public-sector partners in the definition, execution, and assessment of its activities. Widespread use of its research results and swift transfer of its technologies into commercial applications are accomplished through user facilities, cost-shared subcontracts, cooperative R&D agreements (CRADAs), and licensing, as well as publishing, exhibits, and participation in conferences and symposia.

Moderate decreases in funding levels are expected in FY 1997. Funding is then expected to be relatively constant for the remainder of the planning period. New projects are proposed in hydrogen research (program AR) and the industrial sector (program ED).

Electric Energy Systems—AK

ORNL serves as the lead national laboratory assisting DOE in conducting and administering the electric and magnetic fields (EMF) research program. This national program comprises an ongoing core research program to investigate the possible biological effects of power-frequency EMF and the five-year Research and Public Information Dissemination (EMF-RAPID) program mandated by the Energy Policy Act of 1992 (EPACT). ORNL plays a major role in planning and managing these programs, which include work at four national laboratories and several government laboratories, universities, and private research organizations. ORNL is one of four government laboratories responsible for conducting replication studies of EMF bioeffects reported in the scientific literature. In addition to intramural and extramural biological research, ORNL also conducts EMF engineering studies to characterize human exposures and field environments in commercial and industrial settings. Results of the biology and engineering research are provided to the public through ORNL's EMF communication activities for DOE. Public information booklets and a new worker booklet have been developed and widely distributed.

ORNL provides field management of the Superconductivity Program for Electric Systems and also provides assistance in engineering and analytical studies and technical support for planning and decision-making. The goal is to develop the technology base needed for U.S. industry to proceed to commercial development of electric power applications of high-temperature superconductors. The three major elements of the program are wire development, electric power applications development, and the Superconductivity Partnership Initiative. Superconductivity collaborative agreements are the principal mechanism used to enable joint R&D projects with industry and universities; these projects optimize the use of program resources for the benefit of all participants. Major partnerships with industry are under way to take ORNL's patent-pending, coated superconductor technology from the laboratory to pilot production of long wire lengths. The process, called rolling-assisted, biaxially textured substrates (RABiTS™), was developed in partnership with the Office of Basic Energy Sciences in DOE's Office of Energy Research (see Sect. 5.1.1.4). Demonstration of the first commercial lengths of RABiTS™-based wire is expected in FY 1999.

In a collaborative project with Waukesha Electric Systems, Rochester Gas and Electric, and Intermagnetics General Corporation, demonstration of a prototype high-temperature superconducting transformer is scheduled for mid-FY 1997. ORNL is a partner with Southwire Company in a CRADA with the goal of developing technology for a high-temperature superconducting underground transmission cable. A 5-m prototype cable will be demonstrated in mid-FY 1998.

Funding for the Power Transmission and Distribution Technologies Program was eliminated from the FY 1996 budget by Congress, and no future funding is expected. This

program supported ORNL's work with the DOE power marketing agencies, the Electric Power Research Institute (EPRI), and other interested parties to increase electric system capacity, operating flexibility, and energy efficiency while maintaining high reliability. As previously authorized projects are completed, the program will be closed out, with termination expected in FY 1997.

Funding for program AK is expected to remain level during the planning period.

Geothermal Systems—AM

ORNL's work on the physical chemistry of geothermal systems research is focused on providing thermodynamic, isotopic, and kinetic data for input to geochemical models and for prediction and understanding of phase behavior, isotopic distributions, reservoir geochemistry, and corrosion characteristics of geothermal brines. Reactions controlling reservoir permeability, brine chemistry, HCl volatility, and geothermal plant scaling and corrosion are the major concerns of this program, and laboratory investigation of model systems is the approach. Data are obtained on (1) ionization and association equilibrium constants, activity coefficients, solubilities of gases and solids and adsorption of water, volatility of solutes in aqueous solutions and brines, isotopic equilibria, and kinetic processes in the range of 0–350°C and 0–6 molal ionic strength for components of the system H-Na-Ca-Mg-Fe-Al-B-C-Cl-O-S-Si and (2) the thermodynamic mixing properties of silicic melts and the chemistry of aqueous fluids in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–NaCl–KCl–H_2O at 500–2000 bar, 700–1000°C. Our current program emphasizes studies of the volatility of HCl from aqueous solutions to 350°C; aluminum speciation and solubilities in brines to 300°C; isotopic distributions of D/H and 180/160 between liquid and vapor over complex brines to 374; silicate melt-vapor experiments for a range of synthetic granite compositions at 2000 bar, 800°C, and the adsorption of water by reservoir materials.

ORNL is determining, by data collection and analysis, the financial value of the energy, demand, and maintenance savings achieved by the geothermal (or ground-source) heat pump performance contract at Fort Polk, where 4003 family housing units are being converted to the technology. The proper sizing of vertical ground heat exchangers is also being addressed. Funding for the project is expected to continue into FY 1997.

ORNL assisted DOE in planning and preparation of the National Environmental Policy Act (NEPA) documentation and the conduct of related technical support tasks for the Hawaiian Geothermal Project. The project was terminated when the state of Hawaii decided not to pursue the project. ORNL is performing closeout activities focused on archiving the collected data.

Funding for program AM is expected to remain level during the planning period.

Hydrogen Research—AR

The objective of research into hydrogen production by photosynthetic water splitting is the production of renewable hydrogen. This program will build on promising results that have been obtained on the utilization of intact microalgae for photosynthetic water splitting. In this process, specially adapted algae are used to perform the light-activated cleavage of water into its elemental constituents, molecular hydrogen and oxygen. The great potential of hydrogen production by microalgal water splitting is predicated on quantitative measures of the hydrogen-producing capability of these algae. These measures are (1) the photosynthetic unit size of hydrogen production; (2) the turnover time of photosynthetic hydrogen

production; (3) thermodynamic efficiencies of conversion of light energy into the Gibbs free energy of molecular hydrogen; (4) photosynthetic hydrogen production from sea water using marine algae; (5) the original development of an evacuated photobiological reactor for real-world engineering applications; and (6) the potential for using modern methods of molecular biology and genetic engineering to maximize hydrogen production. This project is enhanced by collaborative research between ORNL and senior faculty members at Duke University, the University of Chicago, and Iowa State University. These organizations and faculty members will contribute access to strains and mutants of unicellular algae that may have useful properties for hydrogen production by microalgal water splitting.

A project on enzymatic conversion of biomass to hydrogen investigates the generation of hydrogen gas from sources of biomass (cellulose) using biocatalytic systems that will generate reducing potential sufficient for enzyme-catalyzed hydrogen production. Cellulase catalyzes the hydrolysis of cellulose in biomass to glucose. Glucose has the potential to be oxidized, resulting in hydrogen production. A new in vitro enzymatic pathway for the generation of molecular hydrogen from glucose has been demonstrated. The reaction is based on the oxidation of glucose by *Thermoplasma acidophilum* glucose hydrogenase with the concomitant oxidation of NADPH by *Pyrococcus furiosus* hydrogenase. Stoichiometric yields of hydrogen were produced from glucose with continuous co-factor recycle. This simple system may provide a method for the biological production of hydrogen from renewable resources if certain obstacles can be overcome. Future work will focus on R&D in areas such as increasing the rates of hydrogen production; novel enzymatic pathways for hydrogen production; immobilization of GDH, hydrogenase, and NADP+ for hydrogen production; fermentation of renewables to hydrogen; economic analysis of the system; and metabolic engineering of hydrogenase genes from cellulase-producing bacteria.

In another ongoing project, analyses, computer modeling, and experiments are used to investigate an advanced storage concept for hydrogen using hydrogen adsorption in structured carbon media such as fullerenes. The near-term objectives are to develop a heat transfer model for describing the hydrogen adsorption in fullerenes, to characterize the thermomechanical behavior of the dynamic storage process, and to design practical configurations for thermal hydrogen adsorption-desorption devices. ORNL will also examine efficient thermal management heat-exchange techniques for a range of hydrogen storage options. The study will provide a needed technology database for the practical design and evaluation of storage materials and concepts being developed to facilitate the realization of a clean and efficient hydrogen economy.

Additional proposals are under development for program AR, including the development of low-cost hydrogen detectors to be used as lower explosive limit detectors, leak detectors, and concentration monitors for many applications envisioned by DOE's hydrogen program. Using a concept developed at ORNL, this project will determine the limits of operation, optimize materials and manufacturing, and design the electronics package. Further characterization and design optimization will be carried out through a CRADA with DCH Technology.

Funding for program AR is expected to increase during the planning period.

Hydropower—CE

ORNL conducts R&D to improve environmental assessment and mitigation practices at hydroelectric projects. Technical support is provided to the Advanced Hydropower

Turbine Systems Program, which focuses on development of hydroelectric generating equipment that is more environmentally friendly than current technology. Support is also provided to DOE program offices and DOE's Idaho Operations Office on regulatory issues affecting the hydroelectric industry. Funding in program CE is expected to remain level during the planning period.

Transportation Sector—EB

A program to develop advanced bioreactor systems for alcohol fuel production investigates the use of immobilized biocatalysts for high-productivity fermentation of sugars into ethanol. Several industrial collaborations are being developed to use hydrolyzates from waste lignocellulosic biomass and to test this immobilized-cell fluidized-bed bioreactor with corn sugars at an industrial site. Improved immobilization matrices are being investigated with Du Pont.

ORNL is responsible for DOE's Biofuels Feedstock Development Program (BFDP), The goal of this national program of R&D on crop-based biomass supply systems is to develop environmentally acceptable, economically viable biomass energy crops. The program emphasizes crop breeding and evaluation performed by university and U.S. Department of Agriculture (USDA) collaborators. It also includes environmental research, economic and environmental analysis, scale-up and feasibility studies, and data management and information dissemination. Potential energy crop species are being improved through breeding and genetic studies that emphasize tolerance to biotic and abiotic stresses. Work focuses on trees in the genus *Populus* and on switchgrass (*Panicum virgatum*). During the planning period, the BFDP will include *Populus* development in the Pacific Northwest, the Great Lakes states, and the southeastern states. Switchgrass research will emphasize development of highly productive varieties for the Midwest and Southeast. Working with universities, USDA, and industrial CRADA partners, ORNL will conduct complementary research on genetic control of water use efficiency and on biological limits to productivity. Integrated economic and environmental analysis will characterize the potential production of energy crops across major U.S. farming regions. Environmental research will emphasize quantification of environmental impacts at site and landscape scales, the development of mitigation strategies, and the use of energy crops to promote sustainable development through recycling of agricultural and industrial wastes.

Buildings Sector—EC

ORNL assists DOE's Office of Building Technology, State and Community Programs (BTS) through laboratory and field research in four program areas: Building Thermal Envelope Systems and Materials, Building Equipment Technology, Existing Buildings Research, and Buildings Implementation and Deployment.

Research on building thermal envelope systems and materials is conducted in the Buildings Technology Center (BTC), a national user facility that provides access to world-class facilities for industry and university researchers. Since 1994, more than 200 private users have taken advantage of the BTC to test advanced building materials and construction strategies. Major building envelope research projects include a CRADA with a producer of manufactured housing to examine the energy performance of typical construction details in this cost-conscious industry. Data gathering continues on two reroofing projects that applied ORNL-developed self-drying concepts to test the feasibility of reroofing and adding foam

insulation over an old, wet asphalt roof. Foam-insulated foundations are an important efficiency measure in new houses, but their use in the southeastern United States is limited by concern over termite invasion. A new type of termite-resistant, mortarless foundation block developed and patented by ORNL researchers uses recycled materials to address this concern and maintain the energy performance of foam insulation. A national consumer labeling procedure for whole-building wall thermal performance is under way. Users are testing energy-efficient advanced wall systems in the Rotatable Guarded Hot Box at the BTC. The results serve as the basis for a calculation leading to an overall wall R value accounting for structural interface details (e.g., corners and wall/fenestration couplings). Research projects are under way to improve the energy performance of metal stud walls, commonly used in commercial construction and increasingly popular for residential use.

The building materials program addresses the development and characterization of new and existing insulation materials for buildings and refrigeration equipment. The goal is to develop cost-competitive materials that can reduce building energy consumption by 20% by 2010. Objectives of the program are to develop the technology of powder-filled evacuated panel superinsulation and foam insulations without chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), thereby demonstrating the validity of alternatives to CFC- and HCFC-foamed insulations; to develop improved test procedures for determining properties of advanced and existing materials, yielding accurate and reproducible data for use by the building materials community; and to provide technical support to professional societies and recommend measures that conserve energy. Specific materials objectives are the market introduction of superinsulations with $R > 50$/in. with a 30-year lifetime by 2000; market introduction of HCFC-free foam insulation with $R > 8$/in. by 2004; and market introduction of a wall retrofit insulation with $R = 5$/in. by 1998. Much of the work in this program is performed through CRADAs. Alternative vacuum barrier materials for evacuated superinsulations are being developed and evaluated in CRADAs with Aladdin Industries and with Du Pont and VacuPanel, Inc. The use of evacuated superinsulations in the roof cavities of manufactured housing is being evaluated in a CRADA with Clayton Homes and Tennessee Technological University. The properties of commercially available cellulose insulation are being evaluated in a CRADA with the Cellulose Insulation Manufacturers Association.

The goal of the building equipment technology project is to generate new concepts and develop technologies for improving the energy efficiency and load characteristics of energy conversion equipment used in residential and commercial buildings. The generator-absorber-heat exchange (GAX) absorption residential heat pump technology, developed under an ORNL subcontract with Phillips Engineering Company and licensed to Carrier Corporation, promises heating efficiency at least 50% better than the best current technology and cooling efficiency comparable to middle-of-the-line electric air conditioning. ORNL continues to provide technical support to Carrier in its efforts to bring this technology to the marketplace with a goal of market introduction, initially in small commercial buildings, in FY 1997. The GAX light commercial unit will follow as part of a family of absorption systems that DOE and ORNL plan to bring to the market through industry partnerships. Other products will serve the residential market and eventually the large building chiller markets with high cooling efficiency. Two triple-effect chiller cycles patented by ORNL scientists are under development in DOE partnerships with the gas utility industry and absorption chiller manufacturers.

In other technical areas, ORNL is a national leader in CFC/HCFC research for heating, cooling, and refrigeration applications. The Laboratory collaborates with a historically

black university, Tennessee State University (TSU), to provide data on alternative refrigerants while strengthening TSU's research capability. A CRADA with the Association of Home Appliance Manufacturers (AHAM) is aimed at developing and demonstrating a residential CFC-free refrigerator/freezer that is 50% more efficient than the existing industry standard. AHAM members are scheduled to begin phasing these improvements into their products in 1998. The DOE/ORNL Heat Pump Design Model, widely used by industry, is being upgraded with new refrigerant, refrigerant blend, and heat exchanger capabilities to help heat pump and air conditioner manufacturers meet the product development and redesign challenges of transitioning from HCFCs to next-generation, ozone-safe fluids with improved product efficiencies. ORNL has also developed and patented a technique that extends the liquid-overfeed (LOF) concept to residential air conditioners and heat pumps. A CRADA with the Coca-Cola Company to improve the cost-effectiveness and energy efficiency of vending machines using the LOF technology is nearing completion.

The existing buildings research program supports public and private-sector efforts to improve the energy efficiency of existing residential and commercial buildings. ORNL supports the DOE/Housing and Urban Development Initiative on Energy Efficiency in Public and Assisted Housing by providing technical support and developing guidebooks. A joint effort with the Atlanta Housing Authority continues to explore ways to reduce utility bills in public housing. Other projects include technical support for DOE's Rebuild America program and continuing support of state weatherization programs, in part through training and update of energy audit software.

The main objective of the buildings implementation and deployment program is to foster the adoption and use of energy-efficient and renewable technologies, as well as to ensure that research results are transferred quickly, efficiently, and effectively to public and private-sector users. The program emphasizes strong working relationships with key professional and trade associations and research organizations that serve as intermediaries and brokers in reaching the diverse and fragmented building sector industries, manufacturers, and consumers. The program seeks to identify and carry out technology and information transfer activities that will have a long-term positive effect on the design, construction, and maintenance of energy-efficient and renewable energy buildings and equipment. To this end, the program has built a showcase house in Atlanta, Georgia, that features energy-efficient and renewable technologies developed through BTS research programs and available on today's market. Other products of the program include a regional task force that focuses on building issues in the southeastern United States and a ZIP Code Insulation Program on CD-ROM that assists consumers in determining the insulation requirements of new and existing houses.

ORNL is assisting DOE-EE in addressing the requirements of the EPACT. The Energy Savers initiative is an integrated effort to step up the use of high-efficiency appliances and building equipment through voluntary, joint efforts with public and private-sector partners. Energy Fitness is an element of this initiative, established to encourage increased delivery of energy efficiency to state and local governments and private customers by the performance contracting and energy service company (PC/ESCO) industry. Ongoing restructuring in the electric and natural gas industries creates an environment in which the PC/ESCO industry will be an important vehicle for delivering energy efficiency into the marketplace. The voluntary partners include national associations representing providers and customers of PC/ESCO services and other organizations that can assist in removing barriers to delivery of energy efficiency by PC/ESCOs.

Other projects in program EC include providing technical support to cooperative DOE/industry projects through identification of new and emerging technologies for the home building industry that can improve product quality, energy efficiency, and cost effectiveness; providing technical support to participants in DOE's Industrialized Housing Program; review and analysis of the voluntary efficiency standard being developed by the National Electrical Manufacturers Association for distribution transformers; and technical support to the Federal Energy Management Program.

Funding for program EC is expected to remain level through the planning period.

Industrial Energy Conservation—ED

ORNL's R&D for the Office of Industrial Technologies (OIT) supports DOE's Industries of the Future (IOF) initiative. Seven primary U.S. industries (forest products, glass, aluminum, metal casting, steel, chemicals, and petroleum refining) account for about 80% of U.S. industrial energy consumption and an estimated 80% of total industrial wastes. The OIT has joined in collaborative research paths with these industries. Teams of industry, university, and national laboratory researchers are shaping portfolios of near-, medium-, and long-term research, development, and deployment activities; developing technology road maps and implementation plans; and carrying out cost-shared R&D projects. ORNL also supports cross-cutting areas such as advanced materials, co-generation, technology access, and sensors and controls.

The OIT Advanced Materials Initiative provides new and improved materials and manufacturing technologies leading to energy efficiency in support of the IOF initiative and other national programs in the OIT. ORNL is developing high-temperature ordered intermetallic and metallic alloys that are ductile, corrosion resistant, and strong. Metal-bonded composites are being developed for optimal use at temperatures less than 1100°C. The new Metals Processing Laboratory User Center (see Sect. 6.1.3.2) will enable significant materials development efforts with industries and academia related to the IOF focus. Improved materials are being developed to meet the identified needs of the pulp and paper industry and the glass industry. The uniform droplet process will be used to produce monosized alloy powders for use in developing metallic alloys with controlled microstructures. The R&D addresses the technology base required for materials and manufacturing technology needs in compliance with the mission of the Advanced Materials Initiative and DOE-EE.

ORNL also conducts research and provides technical support to OIT in the development of continuous-fiber ceramic composites, which consist of high-strength fibers in a ceramic matrix. The matrix has the benefits of high-temperature stability, corrosion resistance, and light weight. The fibers embedded in the matrix reinforce and toughen the ceramic, mitigating problems associated with the brittle nature of monolithic ceramics. The properties of the resulting composites make them attractive in a variety of industrial applications where their use can result in energy savings and increased productivity. ORNL provides technical support and assistance in the evaluation of projects and in interactions with industry and the ceramic composite technical community. ORNL conducts an R&D project consisting of tasks on composite design, materials characterization, development of test methods, and performance-related phenomena. This generic research is providing the scientific foundation for successful process development and scale-up by industry.

ORNL and DOE's Oak Ridge Operations Office coordinate the materials and manufacturing element of DOE's Advanced Turbine Systems (ATS) program for power

generation. The objective of this program, which is co-sponsored by DOE-EE and the DOE Office of Fossil Energy, is to develop ultrahigh-efficiency, environmentally superior, cost-competitive gas turbine systems for utility and industrial applications. The technical program plan prepared for the materials/manufacturing element has seven sub-elements: thermal barrier coating development and associated manufacturing issues; development/modification of turbine airfoil alloys, casting processes, and concepts to meet ATS requirements; development of monolithic ceramics and ceramic composites for ATS hot section components and associated manufacturing issues; manufacturing improvements to produce single crystal airfoils; materials characterization; catalytic combustor materials; and technical project management and information exchange.

Other projects supporting the cross-cut areas include a project to provide technical support to DOE and DOE contractors in two general areas: high-pressure and other heat exchanger systems that can improve the efficiencies of industrial processes, and materials technology development focusing on materials and processes to enhance industrial acceptance of ceramic heat exchangers. A new project is proposed to characterize the most challenging industrial process environments for sensors, identify commonalities and opportunities for improving sensor life and performance, and describe ways of mimicking common harsh environments in a laboratory setting to facilitate sensor development and testing. A joint project with industry has been developing high-temperature-lift chemical heat pumps for industrial process and co-generation applications. This project is bringing current activities to an orderly close and will be realigned to support the IOF initiative.

In support of OIT's technology access area, ORNL has a major supporting role in the DOE Motor Challenge program. Showcase demonstration projects are being undertaken by a variety of industries to highlight various approaches to improving the efficiency of motor-driven systems. ORNL works with industrial participants to validate the savings achieved in the projects and publish validated results in case study format; this information can be used with confidence by other industries that have similar opportunities. The Oak Ridge Motor Efficiency and Load program (ORMEL96) gives end users an easy, accurate method for estimating the performance of motors by measuring their speed. Proper identification of energy savings opportunities depends on knowing how motors are used in industry today; however, the last such survey was completed in 1970. ORNL's market assessment activity is directed at developing a database on how motors are used and defining a strategy for updating the database in the future. Excellence Partners are end users who have made a commitment to improving the energy efficiency of their motor-driven systems. Working with DOE and a panel of end users, ORNL has developed and implemented a plan for integrating Excellence Partners in the Motor Challenge.

The Climate Wise program includes a showcase activity to highlight energy-saving projects undertaken by program partners. ORNL provides technical assistance to the showcase teams and performs independent performance validation for the energy-saving results obtained. ORNL is completing a project to provide technical support to DOE in preparation of energy efficiency and economic criteria for the use of thermal insulation by industry, pursuant to Section 133 of the EPACT.

In support of the forest products area, a thermal sciences research project seeks to establish a base of generic knowledge in thermal science relating to advanced pulp and paper processes. The knowledge will be useful in investigations of thermal processes in direct energy conversion, petrochemical applications, or advanced manufacturing. A project is proposed to study high-solids black liquor evaporation, a major technical issue preventing

widespread implementation of a Kraft process called "low kappa," an advanced pulping technology that is more energy-efficient and much cleaner than traditional processes. The study would derive a technology base for equipment design and for developing artificial intelligence–based process control and optimization. Additional proposals for this area are being developed.

In support of the aluminum area, ORNL is developing analytical in-line sensors that will improve the efficiency of commercial aluminum electrolysis operations, thereby reducing energy consumption and cost. Successful completion of this project should also reduce fluorocarbon release by the aluminum production industry and facilitate peak saving for utilities supplying power to aluminum producers. The basic chemistry of the melts will be studied to gain knowledge and speciation of effect of impurities on the process efficiency. The sensors to be developed will be of a Raman spectral type and should have a useful lifetime of six months in the pot-lines. Alumax Corporation, Kaiser Aluminum and Chemical Corporation, and Reynolds Metals Company are actively collaborating with in-kind support in this three-year project. Planned decision points at the end of the first and second years give all parties an opportunity to assess and evaluate the direction of the research.

Several ORNL projects support the chemicals area. The advanced bioprocessing concepts project develops and tests new reactor concepts and configurations for efficient and novel biocatalysis for production of chemicals. ORNL is redirecting into the area of non-aqueous bioprocessing, which offers several advantages over traditional heterogeneous catalysis, including greater substrate solubility and new or improved reactions and separation, that could lead to low energy and environmental costs for production of chemicals. Work will focus on organic-phase biocatalysis in reactor systems. ORNL is also assisting in developing a nomenclature and technology road map. Previous experimental and modeling efforts in gaseous bioreactors, trickling biofilters, and fluidized-bed bioreactors are being concluded. The dehalogenation of process by-products using immobilized biocatalysts is being investigated in a confidential CRADA with Dow Chemical Company. The program also provides support to an annual Symposium on Biotechnology for Fuels and Chemicals.

ORNL conducts R&D on alternative feedstocks for the chemicals and petroleum refining industries. The objective is to develop and demonstrate economically viable technologies and processes for the production of chemical feedstocks from renewable materials, using the production of succinic acid as a representative organic acid. The succinic acid is then purified and converted catalytically into commodity chemicals such as 1,4-butanediol (BDO) and pyrrolidinones. ORNL is providing the technical leadership for this collaborative project; other participants are Argonne National Laboratory, the National Renewable Energy Laboratory, Pacific Northwest National Laboratory, and an industrial CRADA partner, Applied Carbochemicals. The fermentation process for a new microbe is being developed and optimized using a patentable process.

A project on cellulosic waste bioconversion is developing enzyme biocatalysts that will allow economic utilization of wastepaper in fuel and chemical production processes. The main objective of this collaborative project between ORNL and Eastman Chemical Company is to increase the process efficiency for the manufacture of cellulose esters.

Funding in program ED is expected to increase moderately over the planning period as R&D programs are put in place in support of the IOF initiative.

Transportation—EE

The DOE-EE Office of Transportation Technologies sponsors programs at ORNL that explore opportunities for increased energy efficiency in transportation. Through research in materials science, ignition and combustion processes, and innovative manufacturing processes, ORNL provides technologies that enable greater fuel economy and increased use of alternative transportation fuels for both light- and heavy-duty vehicles. Activities funded by program EE are integrated with other ORNL transportation activities through the Oak Ridge Transportation Technology Center (ORTRAN), described in Sect. 6.1.2.

The Partnership for a New Generation of Vehicles (PNGV) is aimed at strengthening U.S. competitiveness by developing technologies for the next generation of vehicles. Government and industry teams are focusing their R&D efforts to attain three interrelated goals:

- Improve the productivity of the U.S. manufacturing base by significantly upgrading the nation's manufacturing technologies and processes.
- Pursue advances in vehicles that can lead to improvement in the fuel efficiency and emissions of standard vehicle designs.
- Within a decade, achieve automotive fuel efficiency improvements up to three times that of the average mid-size sedans while maintaining affordability, performance, and utility of current comparable vehicles.

The Lightweight Materials Program is aimed at developing new, cost-effective, environmentally sound materials and process technologies to enable the U.S. transportation industry to be more energy efficient through vehicle weight reduction. Technical areas supported by this program include aluminum adhesive bonding, fracture modeling of adhesive joints, adhesive environmental durability, nondestructive evaluation for bonded polymer composites, slurry preforming methods and process scale-up, glass fiber preform manufacturing for polymer composites, manufacturability of lightweight electric vehicle structures, aluminum forming, aluminum alloy sheet production and non-heat-treatable sheet products.

Research is under way to apply ORNL's high-efficiency electric motor technology to air conditioner drive systems as a means of reducing the accessory load on an automobile. These systems will also use non-CFC heat pump technology developed by ORNL for additional environmental and energy benefits.

Propulsion systems for next-generation vehicles will most likely be hybrid systems; that is, primary power will be provided by two sources. In most hybrid concepts, the two power sources are a heat engine or fuel cell and a power storage device. ORNL research has produced advances in power electronics efficiency and reliability that will become the cornerstone of the power electronic building blocks of the next-generation vehicle. In addition to applying electric motors and generator technology to these systems, ORNL's work in high-efficiency piston engines and flywheels will be applicable. ORNL's patented resonant snubber inverter has been selected as one of two candidate topologies for the Power Electronic Building Block (PEBB), and ORNL is slated to be one of only two national test sites for first-generation tests of the PEBB. The ORNL Power Electronics Center is leading the standardization effort for the PEBB.

ORNL is one of several DOE laboratories participating in a CRADA with the Super Computer for Automotive Applications Partnership to develop better, faster computer models for the design and manufacture of automobiles.

The Office of Heavy Vehicle Technologies conducts, in collaboration with its heavy vehicle industry partners and their suppliers, a customer-focused national program to research

and develop technologies to enable the U.S. heavy vehicle transport industry to fully exploit the energy efficiency and alternative fuel capabilities of the diesel engine and other potential propulsion systems while simultaneously enhancing air quality.

In the Propulsion System Materials Program (formerly the Ceramic Technology Program), ORNL has developed the technology base for reliable ceramics to be used in advanced heat engines and is now working to reduce their cost, with emphasis on near-term applications in conventional engines. The program has recently been reorganized into two parts, one for heavy-duty diesel engine components and the other for automotive gas turbine applications. Most of the work will be accomplished with the ceramic industry, with technology support from government laboratories and universities. The technology will be developed in close coordination with ongoing DOE and industry engine development programs. Milestones in the program include demonstrating a ceramic life-prediction code for gas turbine and piston engine components in FY 1997 and demonstrating an order-of-magnitude cost reduction in manufacturing ceramic engine components in FY 1998.

ORNL has project management responsibility for emission control, exhaust aftertreatment, and alternative fuel technology in the Heavy Duty Engine program. The Laboratory also conducts supporting research in these areas. Projects are typically led by one of the major U.S. diesel engine companies through cost-shared contracts or CRADAs.

ORNL carries out research in support of advanced piston engines for automobiles through several project thrusts. In CRADAs for the Engine Systems Support Technology Program (the Low Emission Partnership of the U.S. Council for Automotive Research), development efforts are focused on improved diagnostics for emission research, sensors, and catalysts in partnership with the U.S. auto industry. ORNL further provides technical support and research in the four-stroke direct injection engine development effort that is within the framework of the PNGV. In preparation for a substantial role in this program, a small-bore diesel test cell has been established with an engine donated by industry.

Alternative fuels utilization R&D is carried out in complement to the core heavy- and light-duty engine programs. In addition to research on natural gas and alcohols, new efforts have begun to better define the benefits and issues of biodiesel. Much of the on-site research is carried out in the Advanced Propulsion Technology Center in cooperation with the Oak Ridge Centers for Manufacturing Technology (see Sect. 6.1.2).

The High Temperature Materials Laboratory (HTML), one of ORNL's user facilities, houses several dedicated laboratories and special equipment to support the Office of Transportation Technologies, other DOE programs, universities, and industry in advanced materials research. A staff of highly qualified researchers is available to work with participants in the user program in planning and conducting their research and interpreting the results. This combination of state-of-the-art instruments and staff expertise has been very effective. At the end of seven and a half years of operation, in January 1996, 236 nonproprietary user agreements and 45 proprietary user agreements, representing over 600 user projects, had been executed. The nonproprietary agreements were from 121 universities and 115 industries. New capabilities being added include tribological measurement instrumentation this year and a host of new neutron-based capabilities, including neutron radiography and tomography, in the next two years.

The HTML Fellowship Program is directed toward education and technology transfer and accomplishes these missions through graduate, postdoctoral, industrial, and university faculty fellowships. The activity emphasizes research conducted by the fellows using HTML instrumentation capabilities, which can be done intermittently or continuously. During their

one-year appointments, fellows can travel to and from HTML at their convenience (with prescheduled instrument time) to perform research. The HTML Fellowship Program also allows for "reverse" fellowships in which HTML research staff can be temporarily assigned to industry. In FY 1996, seven industrial fellows (from companies such as Ford, General Motors, and Caterpillar) and a faculty fellow were selected. These appointments bring the total to four faculty, ten industrial, and seven graduate fellows since FY 1992.

ORNL conducts analyses of transportation data and energy use related to vehicle R&D, fuel economy, sales, and technology trends. Key transportation energy use data are published in the annual *Transportation Energy Data Book*. Major transportation databases are maintained by ORNL for use by the Office of Transportation Technologies. ORNL analyzes household vehicle usage patterns to better understand the potential market for limited-range vehicles. This understanding is crucial in planning and prioritizing R&D programs for alternative-fuel vehicles—electric and hybrid vehicles in particular. In addition, ORNL provides policy analyses and assessments of fuel economy and clean air considerations.

Moderate funding increases for program EE are expected during the planning period.

Technical and Financial Assistance—EF

ORNL provides evaluation and technical support for several programs in the Office of Building Technology, State and Community Programs. Efforts include continued development and expansion of the National Energy Audit (NEAT) for DOE's Weatherization Assistance Program. NEAT is an advanced computer energy audit tool that assists agency personnel is determining the most cost-effective energy retrofit measures for low-income single-family homes. During 1996, NEAT was used by approximately 500 agencies in 30 states to make retrofit decisions about more than 80,000 low-income dwellings, saving an estimated $70 million in utility costs over standard approaches.

ORNL also provides technical support to the Weatherization Assistance Program by evaluating energy retrofit measures in warm climates, where increased cooling needs and varying housing stock present somewhat different opportunities to save energy than in colder climates. Findings of the studies will assist weatherization agencies throughout the southern United States and will be implemented in NEAT.

In addition, ORNL provides technical support to state weatherization program managers and their subgrantees regarding opportunities to leverage additional weatherization resources from nonfederal sources. ORNL staff have prepared materials and conducted training sessions to enable the weatherization network to better understand and participate in the changing regulatory and economic environment for energy utilities.

ORNL supports DOE's Energy-Related Inventions Program (ERIP), which is directed to assist the development of nonnuclear energy-related inventions with outstanding potential for saving or producing energy, "particularly those submitted by individual inventors and small companies." Since ERIP's inception in 1974, ORNL has systematically monitored the progress of these inventions for DOE. Case studies of ERIP inventions have been completed, and the economic, energy, and environmental impacts of the program have been quantified. Surveys of ERIP inventors have examined characteristics of the technologies, inventors, markets, and business strategies that have contributed to commercial success. Issues related to commercialization, licensing, development cost, and effectiveness of ERIP assistance programs have received special emphasis in the continuing evaluation efforts.

ORNL is also providing technical and management assistance to several international initiatives, including the Asia Pacific Economic Cooperation and two projects of the International Energy Agency: the Center for Analysis and Dissemination of Demonstrated Energy Technologies (CADDET) and the Greenhouse Gas Technology Information Exchange (GREENTIE). CADDET, which maintains an international database of successful energy technologies and focuses on demonstration projects of full-scale applications of new technologies, has two branches: CADDET Energy Efficiency and CADDET Renewable Energy. ORNL is the U.S. Support Office of CADDET Energy Efficiency. GREENTIE maintains a directory of organizations and technologies that promote the reduction of greenhouse gas emissions and serves as a focal point for information and technology sharing among the 21 member countries.

Funding is expected to remain near current levels during the planning period.

Utility Sector—EK

ORNL's research on the electricity industry has dealt with topics related to industry restructuring and competition, as well as resource planning and demand-side management (DSM) programs. Funding for this program has been eliminated, and current tasks are being brought to an orderly close. These include analyses of stranded commitments, options for retail customers, unbundling generation and transmission services (ancillary services), performance-based regulation, analysis of ways to maintain public policy functions ("stranded benefits") in a competitive industry, recent and planned changes in utility DSM programs, and the future of utility DSM. No future funding is expected.

In-House Energy Management—WB

ORNL is conducting energy management studies in Laboratory facilities to identify retrofit projects that will allow achievement of the energy consumption and efficiency goals established by DOE and reflected in ORNL's ten-year energy plan. The goals in the plan are addressed through a comprehensive Energy Management Program. The program's elements integrate energy conservation activities specific to ORNL's buildings, equipment, processes, and vehicles. Heating, ventilation, and air conditioning systems are being upgraded to improve their efficiency.

5.1.2.2 • Office of Fossil Energy

ORNL programs for the Office of Fossil Energy (DOE-FE) cover research in coal, gas, petroleum, and innovative clean coal technology, plus support to the Strategic Petroleum Reserve. The principal focus of ORNL's fossil energy activities is coal. Budgets in this area are expected to remain fairly constant, although the distribution of funds among the various program elements may change.

Coal—AA

The ORNL Fossil Energy Program has the technical lead and responsibility for technical management with DOE's Oak Ridge Operations Office for the Fossil Energy Advanced Research and Technology Development Materials Program. This program covers both (1) traditional structural materials R&D on ceramic composites and advanced alloys and

(2) functional materials (i.e., materials that possess properties important to the performance of specific functions).

Fiber-reinforced ceramic composites with improved strength and toughness are being developed for high-temperature heat exchangers and hot-gas cleanup filters. Ceramic membranes are being developed and tested for the separation of gases in high-temperature and hostile environments. Carbon fiber composite molecular sieves are being fabricated from fibers produced from petroleum and coal-derived pitches. Existing alloys are being modified to produce advanced austenitic alloys for use in fluidized-bed and pulverized coal combustion power plants, with the aim of providing the needed strength and corrosion resistance for high-temperature, high-pressure power plants. Intermetallic alloys, primarily iron aluminides, are being developed for applications in which superior oxidation and sulfidation resistance and strength are required. Oxide dispersions within iron aluminides offer promise of improved high-temperature alloy strengths. Corrosion research centers on studies of the formation and breakdown of protective oxide scales, particularly in sulfur-containing atmospheres. These technologies are being actively transferred to industry and to others in the fossil energy community. A number of licenses and CRADAs have been executed.

Growth continues in the bioprocessing research area. Activities include the conversion of coal to useful liquid and gaseous fuels as well as the removal of heteroatoms and hazardous materials from coal, coal liquids, combustion gases, and other gaseous and liquid effluents and products. Innovative microbial and biochemical pathways for bioprocessing concepts are being investigated for use in these areas, and advanced bioreactor systems that can efficiently and economically carry out such processes are being developed. Other biocatalytic systems are being investigated to remove organically bound sulfur that contaminates coal-derived liquids. Cooperative research with academic and industrial researchers is being conducted in almost all phases of this bioprocessing effort.

Molecular hydrogen is a valuable chemical feedstock for the liquefaction of coal and for hydrocracking and hydrotreating of petroleum. Virtually all hydrogen used in current processes is itself derived from natural gas. Current research is focused on the production of molecular hydrogen via photosynthetic water splitting. This research also receives support from the Office of Energy Efficiency and Renewable Energy (DOE-EE).

Research in the area of coal combustion involves the analysis of fluidized-bed combustion data for deterministic chaos and the development of an electromagnetic mass flowmeter for pulverized coal.

Gas—AB

The development of advanced turbine systems for power generation is the objective of a program jointly sponsored by DOE-FE and DOE-EE. The objective of the Advanced Turbine System (ATS) Program is to develop ultrahigh-efficiency (≥60% in a combined cycle), environmentally superior, cost-competitive gas turbine systems for utility and industrial applications. A supporting element of the ATS Program is the Materials/Manufacturing Technologies Task, which is being coordinated by ORNL to address critical materials and manufacturing issues for both industrial and utility gas turbines. Work is also being initiated to develop methods for eliminating or reducing the amplitude of gas turbine combustion oscillations in fuel-lean conditions. This new work is also expected to have significant application to other important fossil energy processes, including internal combustion engines and utility boilers.

Petroleum—AC

Bioprocessing research in this area involves treating petroleum, petroleum-derived products, and effluent streams for the removal of sulfur, nitrogen, and other contaminants. This activity involves six CRADAs with several major oil companies and bioprocessing firms through the Petroleum Environmental Research Forum, a collaborative effort on the part of these companies. In addition, a new program has been initiated to investigate the biological quality of soils containing hydrocarbons and to evaluate measures to reduce ecological risks through bioremediation techniques. A CRADA is being negotiated to extend advanced membrane technology to the separation of hydrogen from various refinery gas streams.

Innovative Clean Coal Technology—AZ

Work on the Clean Coal Technology Program (CCTP) includes support in the areas of environment and materials. The CCTP is jointly funded by DOE and industrial organizations. All five planned solicitations have been completed by DOE. An important part of ORNL's involvement in the CCTP is environmental technical support to the Morgantown Energy Technology Center in the preparation of National Environmental Policy Act (NEPA) assessments of site-specific projects. Materials failure analyses (critical to the success of clean coal technologies) are conducted for the Pittsburgh Energy Technology Center.

Strategic Petroleum Reserve—SA

ORNL provides assistance to the Strategic Petroleum Reserve Program in the development of models for planning the capacity and management of the Strategic Petroleum Reserve and for analyzing the oil market. A variety of analytical studies using these models have been completed.

5.1.2.3 • Office of Nuclear Energy, Science and Technology

ORNL programs for the DOE Office of Nuclear Energy, Science and Technology (DOE-NE) in support of DOE's energy missions include nuclear energy R&D and isotope production and distribution.

Nuclear Energy R&D—AF

Commercial Reactor Programs • ORNL's current involvement in light-water reactor (LWR) development is primarily in design reviews, general cost studies emphasizing decommissioning cost, and development of specialized technologies such as passive-safety design features and improved control systems. Future work is expected in enhancing the safety margins for existing LWRs deployed in the United States and around the world, including involvement in the DOE cooperative effort with Japan's Nuclear Power Engineering Corporation on LWR technology development and information exchange.

DOE's joint program with the Electric Power Research Institute (EPRI, see Sect. 5.2.2.1) to demonstrate how modern instrumentation and control (I&C) technologies can be used to improve the operational safety margins of nuclear power plants is performed by ORNL and managed through the LWR technology center at Sandia National Laboratories. The program supports the need for most existing nuclear plants to upgrade old I&C systems

because of the lack of spare parts and because of operational and maintenance problems. Equipment suppliers for I&C have replaced older product streams with digital-based products that have yet to be approved by the Nuclear Regulatory Commission for nuclear applications.

Radioisotope Thermoelectric Generator Production • DOE provides radioisotope thermoelectric generators (RTGs) to the National Aeronautics and Space Administration (NASA) for space missions. ORNL produces carbon-bonded carbon fiber insulator piece parts (sleeves and disks), iridium-alloy cladding products (blanks and foil), and iridium powder for use in a heat source portion of the RTGs. This work falls into three categories: (1) fabricating, inspecting, and testing operations; (2) iridium inventory management; and (3) technology development to support the possible use of advanced materials and manufacturing techniques for future NASA missions. Manufacturing and production of blank, foil, and clad vent set hardware and sleeve and disk parts will be undertaken for the anticipated NASA Pluto Express mission, as well as for any other future missions.

In 1997–2002, the Cassini and base technology efforts will be continued (1) to maintain a capability to produce the piece parts and hardware for anticipated follow-on missions after production for the Cassini mission is complete and (2) to obtain materials, material properties, and process improvements that will provide more margin with respect to specification limits, lower costs, and improved yields of sets and hardware. For example, studies have shown that new dopant alloys containing 30 to 40 atomic parts per million (appm) of cesium and 10 to 20 appm of thorium would have substantially better weldability than the currently used DOP-26 alloy, with comparable high-temperature impact ductility and grain growth. Therefore, a new alloy will be scaled up to a half-size ingot to extend the database for prototypically processed material.

Other research will be directed at extending the ultrasonic technique to provide additional engineering data on indication position using time-of-flight measurement and indication characterization using B-scans. Other development activity will include the design and characterization of a carbon-carbon composite structure of cylindrical shape and intermediate density, optimized for maximum energy absorption, to permit qualifying tests as the heat source graphite impact shell.

Initiative

Production of ^{238}Pu in HFIR/REDC

In the past, U.S. supplies of ^{238}Pu were produced in facilities (now closed) at DOE's Savannah River Site. A 1994 review of the capabilities of several DOE sites by the DOE Radioisotope Facilities Task Force determined that ORNL's High Flux Isotope Reactor (HFIR) and Radiochemical Engineering Development Center (REDC), coupled with the Radiochemical Development Facility (RDF) in Building 3019, provide an excellent potential capability for the production of ^{238}Pu and for recycling and chemically purifying ^{238}Pu scrap from various DOE sites.

The ORNL ^{238}Pu production option would involve transfer of neptunium as NpO_2 from the Savannah River Site to the RDF for storage, target fabrication, target irradiation in HFIR, and target processing in Building 7930 of the REDC. These steps, shown schematically in Fig. 5.2, are briefly discussed here. Target irradiation and target recovery could begin as early as FY 2000.

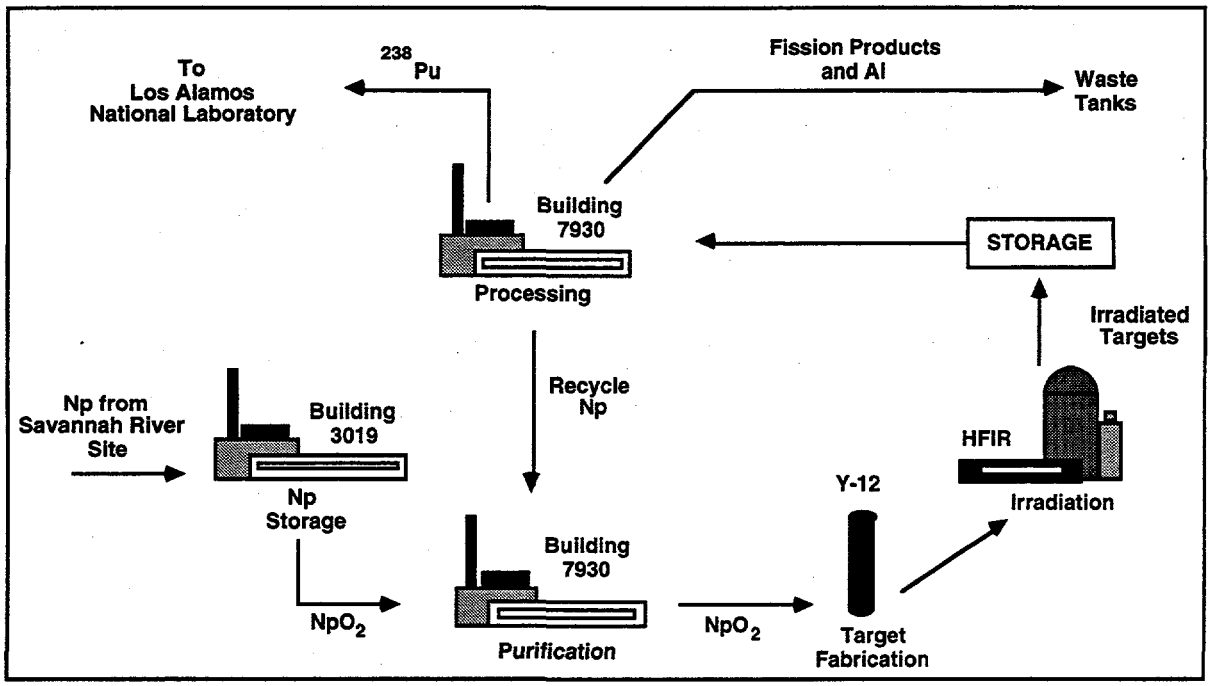


Figure 5.2
Oak Ridge Complex alternative for ^{238}Pu production.

Neptunium storage. The current inventory of neptunium is stored at the Savannah River Site in the form of a nitrate. Plans call for conversion of this material to NpO_2 in 1998 or 1999, yielding about 300 kg of material. The RDF has been identified as the preferred site for neptunium storage. This facility serves as a national repository for ^{233}U and has all necessary safeguards and security systems, as well as appropriate alpha radiation containment and monitoring systems.

Target fabrication. An important aspect of this initiative is the development of an irradiation target design that can be readily fabricated and provide high NpO_2 loading while achieving good heat removal. The reference target proposed by ORNL uses target plates fitted into slotted cylindrical aluminum tubes. Candidate target fabrication facilities are ORNL, the Oak Ridge Y-12 Plant, and the Babcock & Wilcox Naval Nuclear Fuel Division in Lynchburg, Virginia.

Target irradiation. The most cost-effective HFIR option is estimated to produce ≈3.35 kg/year of ^{238}Pu, containing 1 to 5 ppm of ^{236}Pu, from an annual ^{237}Np target loading of 22.1 kg. These calculations and operating experience with the HFIR indicate that the proposed ^{238}Pu production approach should not have a significant impact on other HFIR users, except that the proposed target loading would replace some of the sites now used for iridium isotope production. However, no long-term commitment for iridium isotope production is in place.

Estimated costs. Required start-up activities include facility modifications, equipment purchase, obtaining appropriate operating approvals, and experimentation to support design activities. Cost projections are shown in Table 5.2.

Target processing. Chemical processing of irradiated neptunium targets and scrap plutonium would be performed in Building 7930 of the REDC. The REDC is the production, storage, and distribution center for DOE's Heavy Element Research

Program. Building 7930 is a heavily shielded hot cell facility designed for remote operation.

In planning these activities for the REDC, a process flow sheet was adapted from those previously used at the Savannah River Site and the Hanford Engineering Development Laboratory to determine equipment requirements. The operation was sized for processing 12 kg of ^{238}Pu each year, including irradiated targets from the HFIR (yielding 3.35 kg) and the Advanced Test Reactor (yielding 2 kg), and for recycling ^{238}Pu scrap generated by pelletization and encapsulation at the Los Alamos National Laboratory. This activity confirmed the attractiveness of the two available uncontaminated hot cells located in Building 7930. Because these processing steps are similar to the transuranic processing currently being performed by the REDC, the process is well understood and is thought to represent minimal technical risk.

Table 5.2
Budget projections by fiscal year for ^{238}Pu production at HFIR/REDC[a]
($ in millions—BA)

	1997	1998	1999	2000	2001	2002
Operating costs	2.6	3.8	8.9	10.4	8.0	10.0
Capital	0.4	3.9	6.1	6.3	0.0	0.0
Total	3.0	7.7	15.0	16.7	8.0	10.0

[a]Funding is sought from the Office of Nuclear Energy, Science and Technology under Nuclear Energy R&D—AF.

Isotope Production and Distribution Program—ST

The mission of the Isotope Production and Distribution Program at ORNL is to supply enriched stable isotopes, selected radioisotopes, and related technical services for research, medical, and industrial applications. This continues to be a significant and highly valued program that uses unique capabilities and facilities described in Sect. 6.1.1.3. Radioisotopes are produced in the High Flux Isotope Reactor (HFIR); enriched stable isotopes are produced in the calutron electromagnetic separators located in the Isotope Enrichment Facility at the Y-12 Plant. These isotopes are used for many purposes in research, medicine, and industry. The program mission includes the development and evaluation of methods for isotope production and separation. Specialized technical services such as preparation of high-purity isotopes and unique chemical and physical forms are also performed.

The Isotope Production and Distribution Program receives an annual appropriation for the production of nonprofitable rare isotopes for research uses and isotopes that meet crucial needs in the United States. In addition, the program will continue to produce isotopes for commercial sales when no other supply exists. Guidelines for the program are described in the DOE National Isotope Strategy. The Oak Ridge Center for Isotope Technologies, proposed in Sect. 6.1.3.5, would provide a mechanism for coordinating the resources of the national laboratory system, other organizations (both public and private), and other nations.

5.1.2.4 • Power Marketing Administrations

Bonneville Power Administration

ORNL's Energy Division conducts program evaluation research for the Bonneville Power Administration's Office of Energy Resources. Bonneville has operated a Residential Weatherization Program since 1981. ORNL investigates 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. ORNL will extend its leadership in the fields of artificial intelligence and power systems by developing a system to monitor Bonneville's substation equipment in real time to support reliability-centered maintenance.

The ORNL Environmental Sciences Division provides technical support to Bonneville in evaluating and mitigating the effects of Bonneville's operations on fish populations.

5.1.2.5 • Energy Information Administration

ORNL will continue to support the Energy Information Administration (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 new developments in the following areas of expertise:

- energy, environmental, and economic modeling,
- information systems development,
- creative file structures and maintenance,
- artificial intelligence and expert systems,
- development of an international energy database through the ORNL–U.S. Agency for International Development program (see Sect. 5.2.1.8), and
- a growing number of analyses of technological change.

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

5.1.3 • National Security Programs

5.1.3.1 • Office of Defense Programs

Weapons Activities—GB

Radiation Shielding Information Center • The Radiation Shielding Information Center (see Sect. 6.4.1.2) provides in-depth coverage of the radiation transport field and serves the needs of a variety of disciplines on an international basis.

Technology Transfer Initiative • The Technology Transfer Initiative (TTI) supports R&D that will benefit both programs sponsored by the Office of Defense Programs (DOE-DP) and the private sector. ORNL is engaged in a number of cooperative R&D agreement (CRADA) projects in collaboration with the Oak Ridge Y-12 Plant, focusing on manufacturing. Project teams are made up of staff from ORNL and Y-12 in roughly equal numbers, with leadership provided by the organization with the critical elements for the technology development and transfer process.

A project with very important implications for high-performance computing is aimed at developing the High-Performance Storage System (HPSS). The goal is a network-centered system capable of parallel data transfers at rates in the gigabyte per second range. The HPSS project is a closely linked effort of Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), and ORNL/Y-12 with industrial partner IBM Federal. Additional institutions are involved as early development partners. HPSS is an essential component of DOE's Accelerated Strategic Computing Initiative, and ORNL has a central responsibility in the further development of this system.

As part of the TTI, ORNL operates the Ultraprecision Manufacturing Technology Center, which develops and validates manufacturing processes that can be used to produce affordable, high-quality components. Areas of concentration include precision turning, ductile grinding, ion beam milling, on-process characterization, mechanical design and analysis, and related efficient manufacturing operations. This center is a DOE Deployment/User Facility, where participants from industry, universities, and government perform cooperative, hands-on activities. This concept makes it possible for the private sector to reap the benefits of new technology without incurring the time, expense, and risk of the "trial-and-error" approach to improving manufacturing processes. The Ultraprecision Manufacturing Technology Center is part of the Oak Ridge Centers for Manufacturing Technology (see Sect. 6.1.2).

ORNL coordinates the distribution of some DOE-DP block grants. One of these supports work in collaboration with the gas and oil industry, focusing on National Information Infrastructure (NII) technologies. The goal of the Gas and Oil NII (GO-NII) Testbed is to apply DOE's computational research and system integration abilities in advanced information technologies to U.S. industry issues. In cooperation with LANL, LLNL, and SNL, ORNL and Y-12 are researching dual-use infrastructure needs applicable to both the defense industry and the geographically distributed gas and oil industry. GO-NII projects include synthetic seismic data generation, geophysical modeling, data-distributed visualization, computational steering, hydrofracture studies, information access solutions for the Petroleum Technology Transfer Council, remote collaborative tools, and virtual environments.

Materials Production—GE

The materials production program includes the ^{252}Cf Industrial Sales/Loan Program (co-sponsored by the Office of Energy Research and discussed in Sect. 5.1.1.4), the Mark 42 Processing Program, and the ^{233}U Storage and Distribution Program.

The Mark 42 Processing Program involves the recovery and purification of transuranium element isotopes (^{242}Pu, ^{243}Am, and ^{244}Cm) from Mark 42 targets previously irradiated at the Savannah River Site and segmented at the Pacific Northwest National Laboratory. The Mark 42 targets are processed to recover light transuranium element isotopes for use in weapons diagnostics at LANL and LLNL. Targets are processed at the rate of about 1 target every 18 months. Processing began in 1991; ten targets have been transferred to the ORNL Radiochemical Engineering Development Center for storage and processing.

Shielded, safeguarded storage and some distribution of ^{233}U continue in the Radiochemical Development Facility (Building 3019) at ORNL. Equipment for processing ^{233}U has been in standby since 1989. Plans are being developed to improve the condition of the aging facility to ensure safe, long-term storage and distribution of ^{233}U. An initiative for ^{238}Pu production at ORNL, which involves use of this facility for ^{237}Np storage, is discussed in Sect. 5.1.2.3.

5.1.3.2 • Office of Nonproliferation and National Security

The Office of Nonproliferation and National Security supports R&D activities and technical assessments related to national security requirements. These include work related to chemical sciences and technology, metals and ceramics, instrumentation and controls, engineering technology, biology and health sciences, computational physics and mathematics, energy, robotics and process systems, and solid-state physics.

5.1.3.3 • Office of Fissile Materials Disposition

Fissile Materials Disposition—GA

Major reductions in nuclear weapon stockpiles are creating significant inventories of nuclear material that are excess to military needs. Long-term nuclear weapons concerns and environmental, safety, and health risks posed by these inventories pose a significant challenge to the United States and to other countries. The DOE Office of Fissile Materials Disposition is evaluating strategies for disposition of U.S. excess weapons-capable materials inventories such as plutonium (50 metric tons), highly enriched uranium (HEU) (>50 metric tons), and ^{233}U (>1 metric ton). Near-term options for storage and disposition and ultimate disposition strategies must be addressed.

ORNL is DOE's lead laboratory for reactor-based technologies for fissioning surplus plutonium. ORNL also has the lead for all technologies associated with storage and disposition of ^{233}U and minor actinides (transuranic elements other than plutonium). In these roles, ORNL will have cradle-to-grave responsibility for leading the evaluation and implementation of U.S. strategies for reducing the inherent proliferation potential of these DOE materials. Additionally, ORNL is developing an advanced vitrification technology for plutonium and is supporting Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and Sandia National Laboratories in the development and assessment of other plutonium handling technologies.

Evaluation activities are expected to result in a decision on which technologies for disposition of plutonium, HEU, and ^{233}U will be supported for future evaluation and implementation. Activities in FY 1997–FY 2002 are expected to include R&D on enabling technologies and the start of implementation of the disposition options.

Reactor-Based Disposition of Plutonium • ORNL will lead the DOE effort to evaluate and characterize for a programmatic environmental impact statement (PEIS) the reactor options for converting plutonium into spent fuel. Factors to be addressed include performance, environmental impacts, cost, timeliness, and technical risk.

Implementing R&D, to be coordinated with commercial reactor vendors, will include core design and dynamic reactor controls studies, performance of lead test assembly qualification, examination of the irradiation performance of the Zircaloy-clad mixed-oxide (MOX) fuel, and evaluation of the impact of lower delayed-neutron levels and faster neutronic time scales on the progression of possible severe reactor accidents and source term dynamics and energetics.

A more basic R&D program will be conducted on the use of so-called "deep burn" reactor options for disposition of plutonium with nonfertile fuels. Technologies to be investigated include graphite fuel in a modular helium reactor, dedicated $LiF/BeF_2/PuF$ molten salt reactors, and the plutonium-based graphite particle bed reactor.

Collaborative Studies with Russian Institutes • Under the auspices of DOE, ORNL will conduct collaborative studies with Russian institutes on reactor-based options for

disposition of Russian plutonium. Three collaborative programs on plutonium disposition will be conducted: one with the I. V. Kurchatov Institute on the use of light-water reactors, VVERs, and CANDUs; one with the Physical Engineering Institute, Obninsk, on the use of fast reactors such as the BN-800; and one with the Kurchatov Institute on the use of high-temperature gas-cooled reactors using nonfertile PuO_2 fuel.

^{233}U and Minor Actinides • ORNL will lead a multilaboratory effort to characterize inventories of ^{233}U and other minor actinides and to identify and evaluate options for reducing their proliferation resistance and for their eventual disposal. LANL, LLNL, and the Idaho National Engineering Laboratory will participate in this activity. Options for direct disposition of ^{233}U and minor actinides to the Waste Isolation Pilot Plant or other deep geologic waste facilities will be examined. Methods for co-vitrifying the fissile materials with existing stocks of DOE high-level waste will also be examined.

GMODS Vitrification of Plutonium • ORNL will develop and characterize a novel technology, glass material oxidation and dissolution system (GMODS), for vitrification of metallic plutonium without the currently required steps for converting the plutonium into an oxide. The GMODS technology appears to be particularly attractive for the initial dissolution into borosilicate glass of plutonium scrap and residues. Potential benefits of GMODS include lower cost, reduced environmental impacts, and improved international inspectability of plutonium operations.

Accelerator-Based Conversion of Plutonium • ORNL will support LANL and Brookhaven National Laboratory (BNL) in the development of advanced technologies for the accelerator-based fissioning of plutonium. ORNL will lead the development of plutonium-based graphite fuels in the BNL technology program and will develop plutonium-based molten salt technology, chemistry, and materials of construction in the LANL-led option. ORNL will also conduct a series of system analyses and perform preconceptual facility design for the nonaccelerator parts of the systems.

Transportation Technologies • ORNL will define transportation technologies and evaluate transportation operations and risks for all transportation legs in all program options that involve low-level or high-level radioactive materials. The scope of this task will include transportation of spent MOX fuel in reactor operations, transportation of glass logs with plutonium and high-level waste for immobilization options, and shipments of cesium capsules and low-level waste in several options.

Economic Analysis/Decision Analysis • ORNL will define the economic guidelines and perform life cycle cost analysis for all of the disposition options to be evaluated by DOE. In addition, the ORNL program manager will serve as a member of the DOE Screening Committee for providing supporting assessments for DOE decisions on plutonium, HEU, ^{233}U, and minor actinide disposition. ORNL will also support various DOE public outreach activities by providing technical experts for interfacing with the public and with industrial stakeholders.

Rapid changes in the international nuclear materials situation continue to affect U.S. policies, priorities, and strategies for fissile materials disposition. ORNL will continue to seek new roles and to investigate applications of new technologies to respond to these changing circumstances.

5.1.3.4 • Office of Nuclear Energy, Science and Technology

Naval Reactors—AJ

Radiation Shielding Information Center • The DOE-NE Office of Naval Reactors provides some funding for the Radiation Shielding Information Center (RSIC), which supplies specialized information, computational tools, and a suitable cross-section database to DOE programs by serving as a focal point in the community for technology exchange and making available the latest developments in computing and other technology, data libraries, and bibliographic information. RSIC is described in Sect. 6.4.1.2.

5.1.4 • Environmental Management

5.1.4.1 • Office of Environmental Management

ORNL receives funding from DOE's Office of Environmental Management (DOE-EM) for (1) activities aimed at correcting existing problems, preventing future problems, managing currently generated and legacy waste, and minimizing waste generation at the ORNL site, as described in Sects. 7.3 and 7.4, and (2) R&D and technical support for addressing environmental management problems, principally at DOE sites, with increasing emphasis on technology transfer to the public and private sectors. Much of this activity is conducted by the ORNL Environmental Sciences and Chemical Technology divisions.

Environmental Restoration

Oak Ridge's geologic setting, high rainfall, active groundwater and surface water systems, history of waste disposal, and nearby population centers combine to present environmental restoration challenges that are among the greatest within the DOE complex.

The Environmental Restoration Program effort at ORNL integrates activities supporting transition of inactive facilities for decontamination and release or for demolition with remedial actions for contaminated sites. The program's primary goal is protecting human health and the environment. The ORNL Environmental Restoration Program teams with the Waste Management and Remedial Action Division to provide a comprehensive environmental management program for the ORNL site. The program takes full advantage of the scientific and technical resources at ORNL to meet the local environmental restoration challenges, and it strives to fundamentally improve the process of environmental restoration. Innovative approaches are developed and used to focus and streamline decision making to provide safe and cost-effective risk reduction. The program supports the development and demonstration of technologies for characterization and remediation of sites and facilities, and it collaborates with efforts supported by the DOE-EM Office of Technology Development to demonstrate and/or employ new tools in the remediation process. ORNL scientists and engineers also provide technical support to environmental restoration programs at the Oak Ridge Y-12 Plant, the Oak Ridge K-25 Site, and DOE facilities at Paducah, Kentucky, and Portsmouth, Ohio.

In conjunction with the Surplus Facilities Management Program (SFMP), the ORNL Environmental Restoration decontamination and decommissioning (D&D) program provides surveillance and maintenance to ensure the safety of DOE sites awaiting decontamination or remediation, planning of the orderly decommissioning and stabilization of sites and facilities,

and a program for final disposition. Activities related to cleanup at the ORNL site are described in Sects. 7.3 and 7.4.

ORNL provides support for DOE-EM activities beyond the boundaries of the ORNL site via several remedial action projects (RAPs). Major ORNL activities in RAPs include conducting radiological surveys on private properties near inactive mill tailings sites [Uranium Mill Tailings Remedial Action Project (UMTRAP)] and at facilities that were formerly used under contract with the Atomic Energy Commission [Formerly Utilized Sites Remedial Action Project (FUSRAP)]. The radiological status of sites involved in DOE's RAPs is identified, characterized, and verified to provide a basis for reducing the health impacts of fuel cycle activities. Advancement of the state of the art in equipment and methodology is an integral part of this work.

In support of these activities, ORNL maintains an office in Grand Junction, Colorado. The Grand Junction office leads an effort to identify properties near 24 inactive uranium mill sites and recommend their inclusion in UMTRAP. Most of the inclusion surveys have been completed. The Grand Junction office is also responsible for verifying the adequacy of remedial actions taken to address contamination in excess of relevant Environmental Protection Agency (EPA) criteria and DOE guidelines at UMTRAP sites and at western sites accepted into the SFMP. An ORNL group based in Oak Ridge carries out the equivalent functions for radiologically contaminated sites in the FUSRAP and at eastern sites accepted into the SFMP.

Funding for FUSRAP is expected to remain level. SFMP funding is expected to increase as the level of decommissioning effort at federal facilities increases. ORNL will verify that these facilities are decontaminated in accordance with established DOE guidelines.

New approaches, processes, and technologies are required to tackle many of the pressing environmental restoration problems facing DOE. R&D coupled with demonstration, testing, and evaluation (RDDT&E) is critical to fostering cost-effective solutions to these problems. An important part of the ORNL effort is directed toward RDDT&E in direct support of real problems at DOE sites.

If decontaminated facilities are to be released for unrestricted use, well-documented clearance criteria will be needed. Establishing these criteria will require a definition of the relationship between residual surface contamination and the absorbed dose resulting from skin absorption, ingestion, or inhalation of dust or vapors from surfaces. Staff members in the ORNL Health Sciences Research Division are applying their expertise in radiological surveying and indoor air quality to make measurements and refine models that will be used to develop this definition.

The Energy Systems Groundwater Program Office (GWPO) promotes consistency among groundwater activities at the DOE facilities managed by Energy Systems and acts as a focal point for technical and programmatic interactions with the public and with state and federal regulatory agencies. Groundwater protection program coordinators at each site are responsible for oversight of all groundwater activities at their sites and for facilitating integration of requirements of the compliance and environmental restoration groundwater programs. The Oak Ridge Hydrology Support Program provides technical support to the GWPO to assist in achieving technical consistency and defensibility across the site programs and to facilitate the sharing of lessons learned. Both of these programs are managed through ORNL's Environmental Sciences Division.

Waste Management

Waste management activities at ORNL are discussed in Sect. 7.4. These activities include the operation of 119 facilities, ongoing upgrades of ORNL waste management facilities needed to support the programmatic missions of DOE, and waste minimization activities.

Technology Development

The DOE-EM Office of Science and Technology is charged with developing and demonstrating new technologies for dealing with DOE's environmental management problems. The ORNL Office of Environmental Technology Programs manages a diverse program of technology development to address these problems. The program involves developing new technologies and demonstrating or modifying existing techniques to ensure application of the most cost-effective and technologically advanced remediation and waste management methods. This work is conducted at ORNL, the Oak Ridge Y-12 Plant, the Oak Ridge K-25 Site, and, to a lesser extent, DOE's Paducah and Portsmouth facilities. The technologies being developed are shared among DOE sites and with the private sector for use in solving similar environmental problems. Program components include:

- Subsurface contamination—Characterization, containment, retrieval, and treatment technologies are being developed and demonstrated to address uncontained hazardous and radioactive contaminants in soil and groundwater at DOE sites.
- Mixed-waste characterization, treatment, and disposal—Technology development efforts focus on better and less expensive characterization, retrieval, handling, treatment, and disposal of wastes containing both radioactive and chemically hazardous components.
- High-level waste tank remediation—Safe, reliable, cost-effective methods for characterization, retrieval, treatment, and final disposition of high-level waste in storage tanks are being developed.
- Facility transitioning, decommissioning, and final disposition—D&D technologies focus on the recovery, recycle, and/or reuse of decontaminated building and scrap materials and on material removal, handling, and processing technologies to enhance worker safety and reduce risk.
- Transportation—R&D projects improve the safety, compliance, and effectiveness of DOE's transportation system.

Although some of the technologies mentioned here are currently developed, much more refinement and advancement are necessary for their cost-effective application to increasingly challenging waste problems. Significant industrial involvement is expected, especially during the demonstration phase of the technologies; this will require an efficient transfer of new technologies for application both to and from the DOE facilities. In an effort to increase the number of qualified scientists and engineers, this program also sponsors joint research projects with universities and minority educational institutions to encourage students to study in fields applicable to environmental restoration and waste management.

Significant accomplishments include the successful demonstration of a strontium/technetium solvent extraction process for alkaline tank waste on Melton Valley Storage Tank simulant with >99% efficiency and no generation of secondary waste streams. The KI/I_2 leaching process was successful in removing 96–99% of mercury from mixed waste sediments. The Out of Tank Evaporator System was installed at ORNL, and testing was initiated. A gas phase decontamination technology is being demonstrated at the Portsmouth Gaseous Diffusion Plant.

The ORNL Office of Environmental Technology Programs works closely with private industry, government agencies, and universities to promote innovative environmental technologies. The Lockheed Martin Energy Systems, Inc., Office of Technology Alliances serves as the primary point of contact for technology users and facilitates collaborative activities involving government and the private sector for developing and demonstrating environmental technologies.

Activities are funded by DOE, other federal agencies, and the private sector. The Office of Defense Programs and DOE-EM fund much of the environmental technology work currently being performed at DOE's Oak Ridge facilities.

The Environmental Management Science Program (EMSP) is a new, collaborative initiative administered in partnership by DOE-EM and the Office of Energy Research (see Sect. 5.1.1.8). It is designed to identify and fund basic science research in the areas critical to the cleanup and restoration of the Department's contaminated sites. In FY 1997, ORNL will begin work on 11 projects funded by the EMSP. These projects were selected through a competitive process from more than 810 proposals made by DOE national laboratories, other federal laboratories, industry, and academia.

Quality Assurance and Quality Control

The ORNL Environmental Sciences Division will assist the Office of Environmental Activities (EM-22) in its EM-wide document review, guidance, training, and auditing functions.

Compliance and Program Coordination

For the Office of Transportation, Emergency Management, and Analytical Services (EM-76), ORNL provides evaluations, reviews, technical analyses, and development support in transportation areas related to hazardous materials, including regulatory compliance evaluations and appraisals; evaluation of exemption applications; safety analysis reports; proposed regulations, standards, and orders; formulation of safety-related requirements; and preparation of supporting documentation. The program includes support for the actual performance of compliance appraisals, safety-related program evaluations, and evaluation of regulatory-related activities. Funding is expected to remain stable.

As part of DOE's Strategic Alignment Initiative, the transportation functions of DOE-EM and the package certification functions of the Office of Environment, Safety and Health (DOE-EH) are being merged to consolidate corporate transportation and packaging activities into one Headquarters organization. For FY 1997, ORNL's packaging and transportation safety activities are funded by DOE-EH and are described in Sect. 5.1.4.3.

5.1.4.2 • Office of Civilian Radioactive Waste Management

Nuclear Waste Fund—DB

ORNL's work in support of the DOE Office of Civilian Radioactive Waste Management is being phased out owing to program terminations at the national level. There are no firm plans for future work in this area.

5.1.4.3 • Office of Environment, Safety, and Health

Work is performed at ORNL for the Office of Environment, Safety, and Health (DOE-EH) by nearly a dozen organizations spread throughout the Laboratory structure. This work is coordinated by a program manager for all R&D and technical support activities funded by DOE-EH. The program manager reports directly to the Laboratory Associate Director for Life Sciences and Environmental Technologies. This focal point for communication and coordination provides an effective and responsive interface for the matrix of principal investigators and customers.

Work supported by DOE-EH is described in detail in *Energy Systems Programs for the Assistant Secretary for Environment, Safety, and Health: FY 1995,* ORNL/M-4849, Lockheed Martin Energy Research.

Environment—HA

Technical support activities for DOE-EH include regulatory analysis, analysis of environmental impacts of energy development, technical input to policy analysis, technical guidance on compliance with environmental regulations, and training.

Environmental Guidance and Compliance • ORNL will continue to provide technical support to the DOE-EH Office of Environmental Policy and Assistance (OEPA). Work for this office encompasses a variety of regulatory activities, including the tracking and analysis of regulations and the development and dissemination of regulatory information and guidance. ORNL has provided substantial support for training in environmental laws and regulations, and the development and implementation of training courses in these areas for DOE and its contractors will continue as requested. Efforts will focus on subjects important to DOE's environmental restoration program, such as Resource Conservation and Recovery Act (RCRA) closures, applicable or relevant and appropriate requirements under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Natural Resources Damage Assessment process. ORNL is also assisting in disseminating information from this Office on the Internet.

In addition, ORNL established and now maintains the OEPA World Wide Web (WWW) site (http://www.eh.doe.gov/oepa). ORNL has regularly modified and expanded this site to meet the expectations of OEPA and the changing landscape of the WWW. After examining the feasibility of using the WWW to distribute guidance materials, ORNL placed selected guidance documents on the OEPA WWW site and is working with OEPA to determine which additional guidance materials—including memoranda, documents, guidance workshop materials, and computer codes and documentation—will be placed on the WWW. ORNL also supports OEPA's WWW effort by working with OEPA technical and clerical staff and support subcontractors in developing procedures to minimize time and cost in moving new materials from hard copy to WWW formats.

With assistance from the Oak Ridge Institute for Science and Education (ORISE), ORNL also provided technical support to OEPA in the preparation of the *Environmental Implementation Guide for Radiological Survey Procedures.* Use of this manual will help ensure uniform survey and evaluation procedures and adequate data quantity and quality for radiological environmental assessments. Several chapters of this manual were used as templates for a Multi-Agency Radiological Site Investigation Manual being developed by the Environmental Protection Agency (EPA), the Department of Defense, DOE, and the Nuclear Regulatory Commission (NRC). ORNL staff are also participating in the production of this

document, which is intended to aid agencies in using equivalent survey procedures. NRC has issued a similar draft manual (NUREG/CR-5849) for comment. While limited to license termination surveys, it is generally consistent with similar sections of the DOE manual. EPA is reviewing both guidance documents.

ORNL has the capability to conduct large-scale hydrogeological and environmental characterization activities that are essential to addressing the contamination problems at many DOE sites. Increasing interaction with regulatory agencies is creating the need for a uniform, efficient, and well-organized approach to the development and initiation of site-wide characterization studies. ORNL plans 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 the sites. ORNL technical support in emergency response R&D is available.

NEPA Oversight • ORNL continues to provide technical support to the Office of NEPA Policy and Assistance. This includes assistance with the development of guidance for National Environmental Policy Act (NEPA) compliance, preparation of related background information, review of NEPA documents, and assistance at DOE-HQ. A major initiative, related to the DOE rule on NEPA compliance (10 CFR 1021) and the Secretarial Policy on NEPA, is assistance with the revision of the NEPA Compliance Guide.

Environmental Audit • ORNL expertise in environmental and health risk analysis is available to help identify and prioritize actions required to comply with environmental regulations, Federal Facilities Agreements, and consent orders.

Office of Business Performance Systems • The Environment, Safety, and Health (ES&H) Management Planning Process gives DOE a consistent management tool for addressing ES&H needs at each site. Full integration of this process into DOE's business planning practices and program execution will require further efforts. ORNL will provide support for full integration of this program to assist DOE in its business planning and "Follow the Money" objectives.

Office of Field Support • ORNL will provide technical assistance to support DOE in its expanding program of assistance with issues relating to the safety and health challenges of the Department's decontamination and decommissioning (D&D) mission. The task will focus on

- defining D&D benchmarks,
- developing cost-effective D&D ES&H management concepts and approaches,
- demonstrating concepts through selected pilot projects, and
- sharing results and lessons learned with the DOE complex.

Efforts will be coordinated through involvement with the Office of Environmental Management and other interested participants.

Occupational Safety and Health • ORNL provides technical and management assistance to DOE for several occupational safety and health (OSH) tasks.

- Federal Employee OSH Program. ORNL has helped to ensure the safety and health of DOE Federal employees by contributing to program documentation and guidance, ergonomics program development, analysis of workers' compensation data, and training on violence in the workplace.
- Voluntary Protection Program. ORNL prepares and reviews program documents, provides technical expertise, contracts for external technical support, assists with site reviews of potential candidates, and publishes information.

- Employees Participating in Change (EPIC) process. ORNL developed EPIC as a tool for encouraging workers and front-line supervisors to work in teams to improve safety and health. EPIC is based on the criteria and philosophy of the Malcolm Baldrige Quality Award. The team that developed EPIC received the Secretary of Energy's quality award.
- Order revision and standards streamlining. ORNL has provided major support in reviewing ES&H Orders and analyzing existing requirements for use in the Order revision process. ORNL also helped to develop several of the implementation guides that accompanied new orders.
- Hazardous waste activities. ORNL staff members have been instrumental in supporting these activities. The Laboratory provided technical assistance in the interpretation and applicability of ORNL's Hazardous Waste Operations and Emergency Response Program (HAZWOPER) standard and development of program guidance documents.
- Miscellaneous technical support. Activities include supporting the DOE OSH Coordinating Committee and the ES&H Council, developing OSH guides and manuals, conducting DOE-wide studies and surveys, researching and analyzing motor vehicle safety statistics for DOE, supporting annual DOE safety conferences, developing training modules, operating the DOE Nuclear Criticality Safety Analytical Methods Resource Center, and lecturing on industrial hygiene, occupational safety, and management planning.

Transportation and Packaging Safety • ORNL's Packaging and Transportation Safety Program provides technical and management support for DOE's hazardous materials–related transportation safety activities and responsibilities. As part of DOE's Strategic Alignment Initiative, the transportation functions of DOE's Office of Environmental Management (DOE-EM) and the package certification functions of DOE-EH are being merged to consolidate transportation and packaging activities into one Headquarters organization. For FY 1997, ORNL's packaging and transportation safety activities are funded by DOE-EH.

Oversight assistance has been supplied to DOE by providing technical support and staffing of the assessment teams for DOE-EH site representatives' packaging and transportation performance assessments, the technical assistance program, and the packaging evaluation program. Assistance is also provided in analyzing the packaging and transportation safety implications of reports submitted by contractors to the Occurrence Reporting and Processing System. Occurrence reports and other sources are used to develop Lessons Learned bulletins, which are disseminated to the DOE community to raise awareness and help eliminate recurrence. An electronic bulletin board has been established to provide information on packaging and transportation to the DOE community.

ORNL has drafted a series of DOE Orders on transportation and packaging of hazardous materials, explosives classification, on-site transport, and motor vehicle safety. ORNL also coordinated the efforts to develop the implementation guide for the Order on packaging and transportation safety. Other support from ORNL in the policy and guidance area includes continued work on a packaging design guide and the provision of technical and management support to various national and international guidance and standard-setting committees. Technical assistance to DOE includes technical reviews, paper preparation, maintenance of a listing of current packaging exemptions' status, participation in programs, and management plan preparation.

ORNL also maintains the Standardized Computer Analysis for Licensing Evaluation computational system, SCALE. SCALE is used throughout the world in performing safety evaluations in the areas of nuclear criticality safety, radiation protection, radioactive material characterization, and heat transfer. Upgrades and corrections to the system are available to

users through the Radiation Shielding Information Center at ORNL (see Sect. 6.4.1.2). A SCALE Users Training Course is conducted by project staff at ORNL. Course attendees include representatives from DOE, the Nuclear Regulatory Commission, national laboratories, and industry, plus a number of international participants.

Biostatistical Support for Health Studies • ORNL continues to provide the Deputy Assistant Secretary for Health Studies with statistical support for programs in epidemiologic surveillance and occupational medicine. Statistical methods being developed to describe and evaluate illness and injury event data will be used by DOE's Epidemiologic Surveillance System, which will monitor the health of the work force at all DOE sites and will be used to identify health hazards in the work place. The Office of Occupational Medicine and Medical Surveillance is conducting a follow-up study of beryllium workers at the Oak Ridge Y-12 Plant. The beryllium lymphocyte proliferation test is being used as part of a screening procedure to identify individuals who may have chronic beryllium disease. Statistical methods that will facilitate the evaluation of this test are being developed. ORNL provides general biostatistical support to the Office of Epidemiologic Studies for the planning, analysis, and interpretation of studies related to health and environmental issues.

Nuclear Safety Policy and Standards—HP

ORNL provides technical and administrative assistance to the Office of Nuclear Safety Policy and Standards, System Analysis and Standards Division, in the development of rules, orders, safety guides, standards, and supporting documents in the areas of Safety Analysis Reports, Technical Safety Requirements, worker safety, and other areas as requested.

DOE Technical Standards Program • ORNL responsibilities for the DOE Technical Standards Program are

- to function as the DOE lead contractor for the program;
- to develop new program procedures for use in implementing the DOE standards policy and the National Technology Transfer and Advancement Act of 1995 (P.L. 105-113), which requires Federal agencies to use and assist in developing voluntary standards in lieu of internal standards;
- to develop and maintain a DOE standards database;
- to compile and disseminate information on standards;
- to develop and conduct program briefings and workshops for DOE and DOE contractor personnel on the DOE Technical Standards Program; and
- to provide technical support for DOE standards committees and voluntary standards organizations.

Operating Experience Analysis and Feedback—HP

DOE Performance Indicator Program • DOE considers that facilities with good performance, as measured by performance indicators, are generally recognized as well-managed facilities. The objective of DOE's performance indicator program is to collect data on key ES&H performance indicators and analyze the data for relevant trends and patterns. ORNL compiles and prepares quarterly DOE-level ES&H performance indicator reports for senior DOE leadership and performs special analyses of these data as requested. In addition, ORNL provides technical assistance in developing new approaches for performance data analysis and depiction, conducting workshops and meetings on performance measurements

and performance indicators for DOE and contractor personnel, and evaluating sources of performance indicator data.

Occurrence Reporting Quality Analysis • Clear, concise, and timely information on occurrences at DOE facilities is essential to learning from operational experience. ORNL periodically selects random populations of occurrence reports from DOE sites and analyzes them for trends and patterns in data quality and timeliness. The results of these assessments are made available to the DOE community. ORNL also provides support for addressing customer/stakeholder feedback received on needed improvements in the occurrence reporting process.

5.1.5 • Other DOE Programs

ORNL provides support to other DOE offices and installations, including the Assistant Secretary for Policy, the Federal Energy Regulatory Commission, and other DOE contractors and operations offices.

5.1.5.1 • Assistant Secretary for Policy, Planning and Analysis

Policy Planning and Analysis—PE

Work for the Assistant Secretary for Policy, Planning and Analysis will include research on transportation, energy efficiency, infrastructure costs associated with alternative fuels, alternative fuels supply issues and effects on energy security, consumer choice and demand issues for alternative fuels, fuel economy standards for automobiles and light trucks, and energy options for developing nations. Research will continue on the effects of clean fuels and reformulated gasoline on the energy industry, consumers, and the environment. ORNL anticipates continuing work in support of DOE's role in assisting the Council on Environmental Quality in the development of a national strategy and plan for reporting long-term environmental trends. Additional support is provided in the area of regulatory analyses for hydropower development and environmental compliance issues.

ORNL supports the Office of Environmental Analysis and Sustainable Development in developing energy resource assessment models and providing background research for various energy and environmental policy issues. This office is funding a variety of projects, including a flue-gas desulfurization information system, development of a residual generating model for the National Energy Modeling System, studies of international developments in global climate change, research on the physical and ecological effects of climate change, research on the economic valuation of energy-related environmental impacts, and studies of the impacts of environmental policies on electric utilities. A major effort is in progress to analyze fuel cycles and to provide estimates of (1) the physical impacts on environmental resources, including human health and safety, and (2) costs and resulting potential effects on market prices for major fuels.

ORNL also provides support on hydropower issues (e.g., by studying the feasibility of a hydropower environmental mitigation information analysis system). If DOE continues to support this concept, additional long-term funding may be received.

ORNL is actively involved in developing a DOE program related to the energy needs of developing nations. The Assisting the Deployment of Energy Practices and Technologies (ADEPT) Program includes needs studies, technical information, institution building, training, technology adaptation, and technology demonstration. ORNL roles include project

activities and program support. In addition, ORNL is supporting the development of an Energy Efficiency Strategy Assistance Program.

5.1.5.2 • Federal Energy Regulatory Commission—VR

ORNL provides assistance to the Federal Energy Regulatory Commission (FERC) in two major areas: (1) environmental, economic, and engineering assessments that support licensing of nonfederal hydroelectric projects, and (2) additional studies related to compliance with FERC license conditions or other environmental regulations at existing projects. Ongoing work includes development of a site-specific NEPA document on the Tuolumne River in California, where competing water uses are being evaluated, and studies in the state of Washington, where 17 small-scale projects are proposed in the Skagit and Nooksack river basins, and in Montana for a nine-dam relicensing action on the upper Missouri and Madison rivers. ORNL is also supporting FERC in a programmatic study of the cumulative effects of all hydropower projects in California's Central Valley; this study is related to coordinated federal and state regulatory proceedings to solve environmental quality problems in the Sacramento–San Joaquin Delta. ORNL develops complex computer models to predict the environmental benefits and socioeconomic costs of mitigation alternatives. Issues of national importance are addressed, such as biodiversity, endangered species, and reallocation of water resources. Relicensing of existing projects has become a major effort for the FERC, and ORNL staff are working to define methods to enhance an environment that may have been affected by 50 years of hydropower operation.

5.1.5.3 • Other Programs

ORNL performs numerous small tasks, frequently on an ad hoc basis, for a number of other organizations within DOE; the Economic Regulatory Administration; DOE's Oak Ridge Operations Office; and others. These activities are distributed among the various Laboratory programs and together make up about 5% of ORNL's total funding.

Managers at Oak Ridge sites and the Portsmouth Gaseous Diffusion Plant continue to need new or better field screening tools in the assessment of environmental restoration needs at their plants. Staff from the ORNL Health Sciences Research Division field-test newly developed analytical techniques at these sites. In addition, they provide a rapid-response, field-portable, analytical capability to address unforeseen needs at these sites.

Biological monitoring continues to be an important activity for complying with National Pollutant Discharge Elimination System (NPDES) permits and demonstrating the efficacy of environmental restoration activities. The Environmental Sciences Division takes the lead in conducting and managing biological monitoring activities at all three DOE Oak Ridge sites, at Portsmouth, and at the Paducah Gaseous Diffusion Plant.

The Knolls Atomic Power Laboratory provides support to ORNL's Computational Physics and Engineering Division for the continuing development of TORT, the Three-Dimensional Oak Ridge Transport Code. Emphasis is on developing new code features, options, and improvements that are crucial to the modeling of large, complex shield geometries. The goal of this research is to significantly reduce job execution time, central memory requirements, and input/output file size. Near-term activities include the development and implementation of iteration acceleration techniques for convergence enhancement, multitasking capabilities for operation on parallel processing computers, and code-to-code coupling technologies for "bootstrapping" calculations.

5.2 • Work for Others

5.2.1 • Federal Organizations

5.2.1.1 • Nuclear Regulatory Commission

ORNL efforts for the Nuclear Regulatory Commission (NRC) reflect the Commission's priorities: response to public attitudes requiring a high degree of confidence in the safety of nuclear power, the maturing of the current generation of U.S. nuclear reactors, and certification of the next generation of reactors. Completion of the more than 100 nuclear plants ordered in the 1960s and 1970s, coupled with the upcoming expirations of operating licenses for many of these plants, has shifted the emphasis of NRC research toward structural and component safety issues, structural aging research, analysis of reactor operational data, advanced instrumentation and diagnostics, accident sequence analysis, and license renewal requirements. The NRC is also in the process of certifying advanced light-water reactor (LWR) designs. Funding from the NRC supports work in each of these areas at ORNL; amounts are expected to trend slightly lower over the next several years as the NRC's budget is reduced and the use of internal staff increases.

ORNL performs work primarily for three offices within the NRC: the Office of Nuclear Regulatory Research (RES), the Office for Analysis and Evaluation of Operational Data (AEOD), and the Office of Nuclear Material Safety and Safeguards (NMSS). RES, the major sponsor of ORNL activities, conducts comprehensive research programs that lead to regulatory guidelines and standards issued by the NRC. AEOD collects, analyzes, and evaluates operational safety data to identify areas requiring NRC or industry action. NMSS is charged with overseeing public health and safety licensing activities in the nonreactor nuclear arena.

Nuclear Regulatory Research

During the planning period, the NRC will continue to give priority to investigating long-term behavior of reactor pressure vessels (RPVs), severe accident issues, instrumentation and controls technology, and issues relating to renewal of the operating licenses of existing power plants beyond their original 40-year period. As part of their activities in support of the NRC, ORNL staff members will hold positions in relevant domestic and international organizations and committees. International organizations include the Committee on Safety of Nuclear Installations of the Nuclear Energy Agency (an agency of the Organisation for Economic Cooperation and Development) and the International Atomic Energy Agency (IAEA).

To support license renewal, ORNL conducts aging studies of engineered safety components such as valves, pumps, and piping, including reliability assessments. ORNL has also developed a structural aging handbook and a materials property database for aging concrete structures in U.S. nuclear power plants. Current efforts involve the development of criteria for use in estimating future structural capacity margins for steel containments and liners.

ORNL contributions to the NRC's Severe Accident Research Program (plan documented in NUREG-1365, Rev. 1) include work on boiling-water reactor (BWR) core-melt

progression and in-vessel strategies for addressing potential severe accident conditions. ORNL staff collaborate with Sandia National Laboratories and the Idaho National Engineering Laboratory to improve the MELCOR and RELAP/SCDAP codes for LWRs and extend their applicability to scenarios for severe accidents in BWRs. Other severe-accident code development work supports NRC cooperative research agreements with seven nations to develop and validate computer codes for modeling fission product behavior and core-melt progression under severe accident conditions (Cooperative Severe Accident Research Partners). Support is provided for other NRC-developed codes such as CONTAIN.

The NRC continues to place high priority on research to ensure the integrity of RPVs in commercial nuclear power plants. ORNL is the lead laboratory for this work, which includes the Heavy-Section Steel Technology (HSST) program, the Heavy-Section Steel Irradiation (HSSI) program, the Embrittlement Data Base and Dosimetry Evaluation program, and the Annealing Demonstration Evaluation program. The NRC integrates the results of these programs into its reactor regulation process and into its agreements with foreign states (e.g., the activities of the Joint Coordinating Committee for Civilian Nuclear Reactor Safety with Russia and other states of the former Soviet Union).

The HSST program investigates issues concerned with validating safety margins for prevention of reactor vessel fracture under all feasible loading conditions. Large-scale fracture experiments and advanced analysis methods are used to investigate the impact of shallow flaws, multiaxial loadings, and localized thermally induced constraints in association with emergency core-cooling scenarios. Results of experiments are factored into national consensus standards and NRC procedures. The support will continue to include supplemental pressure vessel safety research for advanced LWR designs that the NRC is in the process of certifying.

The HSSI program is extending databases and the basic understanding of physical mechanisms associated with radiation-induced damage (e.g., embrittlement) in pressure vessel steels. Base metal, welds, and cladding are included. Radiation experiments are performed to verify the applicability of damage models to prototypically thick sections of each material. The program includes studies of the degree to which degraded steel properties recover when thick sections of irradiated steel are annealed at relatively high temperatures for long periods of time. R&D activities relating to irradiation embrittlement of RPV steels continue to be considered of the highest priority to nuclear safety by the NRC and the international community. Assistance is given to the NRC's consideration of the state of embrittlement of specific operating plants.

The Embrittlement Data Base and Dosimetry Evaluation program maintains for the NRC the national operational surveillance database on embrittlement of pressure vessels in commercial and research reactors. These data are used to develop improved correlations for predicting the state of embrittlement; the results have direct applications in license renewal and life-extension assessments, which will continue to be major NRC concerns. Attention is given to determining the compatibility of data from other nations with the U.S. database and to possible combination of these data. ORNL leads the NRC effort to develop and examine an international database on embrittlement; this effort is coordinated with the IAEA.

DOE is conducting an annealing demonstration program on unirradiated RPVs at the abandoned Marble Hill and Midland-2 nuclear plants. ORNL conducts the NRC associated annealing demonstration evaluation program, the purpose of which is to independently evaluate the engineering feasibility of annealing U.S. RPVs. Data and analysis results from

the demonstration program will be used to support future applications to NRC for licensing approval of RPV annealing procedures and equipment.

ORNL has worked with the NRC to develop and finalize a Generic Environmental Impact Statement (GEIS) appropriate for license renewal rulemaking. The NRC is currently reviewing the need for further public comment.

The NRC sponsors safety research to support certification of advanced LWRs. ORNL provides support in the areas of thermal hydraulics code validation, assessment of severe accident evaluation, instrumentation and control methodologies, and pressure vessel and materials studies. ORNL's support in this area is expected to remain constant as the NRC continues its considerations of advanced reactor designs such as the AP600.

The journal *Nuclear Safety*, funded by the NRC and coordinated by ORNL staff, provides safety information to the nuclear industry. Publication is expected to continue.

Analysis and Evaluation of Operational Data

ORNL projects sponsored by AEOD, which serves as a focal point for the continuing independent assessment of operational performance of nuclear power plants, emphasize the collection, review, analysis, and evaluation of plant safety performance data. Support to AEOD is expected to remain roughly constant.

The Accident Sequence Precursor (ASP) project identifies nuclear power plant events that are considered precursors to accidents with the potential for severe core damage and uses risk assessment methodologies to determine the quantitative significance of events. ORNL is assisting in the resolution of operational performance issues, benchmarking the operating records of individual power plants for diagnostic assessments, trending events, providing technical assistance, and responding to inquiries from NRC staff on operational and safety-related issues.

ORNL operates and maintains the Sequence Coding and Search System (SCSS), the NRC's official database on reportable operational events at commercial power plants. SCSS is a highly structured system that supports detailed searches of operational occurrences, ASP analyses, the NRC's performance indicator programs, and identification of common-cause failures. ORNL also maintains data systems on reactor events in other nations, international incident reports, and power plant performance indicator data and appropriate statistical models developed for the interpretation of these data. ORNL provides support to AEOD through the NRC's performance indicator program by evaluating events to determine their cause, monitoring changes in plant performance, and compiling corrective action data needed to prevent plants from developing serious problems.

Nuclear Material Safety and Safeguards

NMSS currently sponsors a number of projects at ORNL. Most of these are expected to continue, and new projects are expected to take the place of those that come to an end. NMSS funding at ORNL is expected to remain at about the current level or to increase slightly over the planning period.

For the Division of Fuel Cycle Safety and Safeguards, current projects include technical support for nuclear criticality safety analyses; assessment of technical criteria for the termination of safeguards on nuclear material contained in irradiated waste; safety and environmental review assistance; technical assistance in the preparation of the *Standard Format and Content Guide* and the *Standard Review Plan* for license applications for fuel

cycle facilities; nuclear awareness seminars for multiple-agency threat analysts; technical assistance for Russian, Ukrainian, and Kazakhstani material protection, control, and accounting; technical assistance for licensing of uranium enrichment facilities; and technical assistance for assessing the effectiveness of the low enriched uranium reform rule and its implementation.

For the Division of Industrial and Medical Nuclear Safety, current projects include cask analysis and review, general license inventory system management and analysis, safety and environmental review assistance, and review of terminated license files.

For the Division of Waste Management, current projects include technical support to the Ukrainian State Committee for Nuclear and Radiation Safety on specific waste issues and technical support for design, construction, operation, and performance reviews for low-level waste.

Other Offices

ORNL provides technical assistance to the NRC Office of State Programs in the review of Agreement State regulations and programs, to the Office of Nuclear Reactor Regulation in evaluations of BWR stability phenomena and in design reviews of advanced LWRs, and to the Office of Information Resources Management in the areas of information management and model development.

5.2.1.2 • U.S. Department of Defense

ORNL provides R&D support to the defense and national security community where the Laboratory's mission coincides with the mission of the Department of Defense (DOD) and related security agencies. Programs in this area are conducted in close cooperation with Lockheed Martin Energy Systems, Inc., and include basic and applied research and technology demonstration programs.

ORNL provides special high-strength, lightweight materials for advanced armor for protection of civilian and military personnel, armored vehicles, satellites, and other high-value assets. Advanced material processing also supports development of new penetrators and penetration systems, high-temperature nose cones, and related weapon components.

Work continues to develop miniaturized sensors and intelligent sensors on a chip for point contact and stand-off detection of chemical and biological agents. New instrumentation and sensors are also being developed to improve detection of land and marine mines from land-, air-, and marine-based systems. This work will be conducted in collaboration with other DOE national laboratories.

Improved diagnostic and prognostic systems support the manufacture, life extension, and maintenance of weapon systems. Novel approaches to secure communications and computing are being developed for the safe transmission of information for national security and business applications.

Autonomous and teleoperated robotic systems are developed for remote navigation in hazardous environments for site characterization and restoration and for safe handling of hazardous materials. Remote handling technologies are also used to rearm ammunition for military ground combat vehicles, aircraft, and air defense missile systems.

Work continues to develop transportation and logistics models for defense customers, including transportation planning and tracking for rapid military response planning and execution for international contingencies. Environmental research is conducted to better manage

military base operations as well as to support the closing, restructuring, and modernization of military bases and facilities. New technology is developed and evaluated to avoid or reduce pollution from DOD manufacturing programs. Energy research supports new energy conservation technology for military housing and power supply systems, as well as more efficient vehicle and transportation systems. Work continues to provide demographic and economic modeling support for planning, recruiting, and retention of military personnel. ORNL will continue to seek new opportunities to use its special expertise and facilities to support the critical issues and requirements in the defense and national security community.

5.2.1.3 • National Aeronautics and Space Administration

The NASA Earth Observing System Data and Information System (EOSDIS) is a key component of the U.S. Global Change Research Program. ORNL is one of nine Distributed Active Archive Centers (DAACs) through which the scientific research community can acquire data and information from EOSDIS. The ORNL DAAC is described in detail in Sect. 6.4.1.2.

5.2.1.4 • U.S. Department of Health and Human Services

The U.S. Department of Health and Human Services supports research in carcinogenesis, protein engineering, protein crystallography, genetics, and toxicology. Funding from this source is expected to remain reasonably constant over the planning period. The majority of funding is from the National Institutes of Health (NIH); some funding is from the U.S. Food and Drug Administration (FDA).

Genetic, reproductive, and general toxicology databases (see Sect. 6.4.1.2) are being developed, analyzed, and evaluated for the FDA, the National Library of Medicine, and the National Toxicology Program, with support from the Environmental Protection Agency.

The National Cancer Institute (NCI) supports research on the expression of preneoplastic markers in tracheal cells. ORNL is studying cell interaction and the role of transforming growth factor–beta (TGF-β) in the control of tracheal cell proliferation. With the National Heart, Lung, and Blood Institute, NCI also sponsors work in the ORNL nuclear medicine program to develop a basic understanding of the chemistry and physiology of cerebrovascular and cardiovascular imaging agents. A new NCI project will link the cancer and acquired immunodeficiency syndrome (AIDS) registries at 15 sites across the United States, emphasizing approximately 80% of the known human immunodeficiency virus (HIV)–AIDS population. This information is anticipated to be used in determining course of treatment, disease progression, and mechanisms of action.

The National Institute for Child Health and Human Development (NICHHD) supports a program on the induction of insertional mutations by means of transgenic technology. Caused by integration of foreign DNA into the host genome, such mutations are valuable for correlating gene structure with function. NICHHD also supports research on fundamental cryobiology and preservation of mouse sperm, complementing cryobiology research funded by DOE's Office of Health and Environmental Research.

The National Institute of General Medical Science supports studies to improve the understanding of hydrogen-bonded biological systems.

For the National Institute for Environmental Health Sciences (NIEHS), ORNL is enlarging the database on the response of germ cells to chemicals. The induction of both gene mutations and chromosome aberrations is being measured, and these genetic lesions are

being studied in depth. ORNL has also developed a computerized database on transgenic mice and is mapping transgene integration sites. The Environmental Mutagen Information Center (see Sect. 6.4.1.2) also receives support from NIEHS.

The National Institute on Aging supports frozen embryo banks for several mouse and rat strains developed for aging studies. For the National Institute of Allergy and Infectious Diseases, ORNL is investigating a mouse autoimmune disease that may be a model for disorders of the human immune system. ORNL is also studying the pathogenesis and molecular genetics of polycystic kidney disease for the National Institute of Diabetes and Digestive and Kidney Diseases. For the National Institute of Dental Research, ORNL is studying the molecular genetics of cleft-palate development and determining the role of a candidate gene by transgenic rescue experiments.

5.2.1.5 • U.S. Environmental Protection Agency

ORNL's work for the Environmental Protection Agency (EPA) addresses numerous health and environmental problems and issues.

- ORNL provides technical support to the National Acid Precipitation Assessment Program II in the development of the Program Operating Plan and the plan for the program's periodic assessment reports to Congress.
- ORNL staff support the ecological risk activities of several EPA program offices, the Risk Assessment Forum, the Office of Water, and the Office of Pesticide Programs. This work includes efforts in water quality criteria and soil quality criteria, with continuing research on the effects of acid deposition on high-elevation forest ecosystems, and reviews of toxicology data submitted to EPA by potential pesticide registrants.
- ORNL staff and the staff of the University of Tennessee's Center for Clean Products and Clean Technologies are working with EPA scientists on the Design for the Environment Program, which is aimed at helping industry incorporate environmental considerations into the design and redesign of products and processes.
- EPA is supporting research at ORNL to evaluate the use of physiologically based pharmacokinetic models in the risk assessment process.
- Work continues on the Environmental Mutagen Information Center database, described in Sect. 6.4.1.2.
- Literature reviews and chemical hazard information profiles are prepared for EPA-selected topics and chemicals. The Chemical Unit Record Estimates database (see Sect. 6.4.1.2), which provides comprehensive summaries of risk assessment parameters and values derived from more than 3000 EPA chemical exposure documents, serves as a research tool for EPA scientists. ORNL also develops reference dose and reportable quantity profiles that help reduce uncertainty in risk assessments.

In April 1996, EPA officials visited ORNL to discuss the possibility of forming a research partnership with the Laboratory. The discussions focused on the identification of areas in which the technical and financial resources of EPA and DOE could be shared through a pilot program at ORNL to pursue pressing national environmental research needs, with emphasis on four topics:

- identifying areas where more closely coordinated research will be mutually beneficial to each party;
- identifying research areas where resources can be leveraged to allow for greater progress;

- discerning the unique facility capabilities of each organization so that equipment can be shared; and
- identifying areas where each organization will be taking the lead for the federal government.

Interactions aimed at building this partnership will continue during the planning period.

5.2.1.6 • National Science Foundation

Research sponsored by the National Science Foundation (NSF) examines a variety of environmental concerns. The NSF supports studies of spatial gradients in nutrient cycling and their effect on stream ecosystem stability, drawing on the Walker Branch Watershed and using radioisotope tracers to research key factors in stream response. The understanding derived from this research will benefit ORNL studies of disturbed aquatic systems on the Oak Ridge reservation that are being conducted in concert with remedial action efforts.

ORNL continues to provide technical assistance to the NSF Division of Polar Programs in evaluating the environmental impacts of the U.S. Antarctic Program. ORNL is developing site- and project-specific environmental impact assessments, with emphasis on waste and fuel management, sensitive resources, and global concerns for the Antarctic.

The NSF supports research to evaluate the scientific bases for assumptions used in risk assessment. The results are intended for use by federal agencies responsible for regulating human exposure to chemical carcinogens. The NSF also supports a program to develop methods for maintaining genetic lines of *Drosophila* in a frozen state. New cryopreservation techniques being developed at ORNL have the potential to replace cumbersome and costly traditional breeding techniques.

The NSF's Industry/University Cooperative Research Program funds the University of Tennessee at Knoxville's Measurement and Control Engineering Center, a collaboration with ORNL and a variety of industrial partners. The Measurement and Control Engineering Center has capabilities related to analytical instrumentation, process controls, signal/image processing, and predictive maintenance.

The NSF also provides funding for the National Center for Environmental Decision-Making Research, which is part of the Joint Institute for Energy and Environment (see Sect. 6.2.1). The center will develop new study methods, analysis tools, and processes to help government and private enterprise make use of scientific research in their environmental decision-making.

5.2.1.7 • Federal Emergency Management Agency

ORNL programs for the Federal Emergency Management Agency (FEMA) include a range of research, development, and technical assistance activities in support of national preparedness for major emergencies. At FEMA's request, ORNL serves as an independent center of expertise in areas ranging from engineering assistance to analysis and assessment.

Engineering work includes assisting in hardening civil defense installations against electromagnetic pulse effects, developing devices that protect against the effects of electromagnetic pulses, and testing equipment. Analysis and assessment activities include building economic models of preparedness options, assisting with the use of computer graphics, studying human behavior in emergencies, and working on state-of-the-art assessments on various programs and issues. These activities also include

- development of a national system for infrastructure information,
- emergency preparedness for hazardous material accidents, including those involving chemical weapons,
- impacts of disasters,
- postdisaster economic recovery,
- data sources for emergency management,
- shelter concepts for emergency protection,
- civil defense program planning,
- risk communication and public awareness,
- evacuation planning for natural and man-made disasters,
- public alert/notification system performance,
- preparedness for special populations and institutions, and
- adequacy of training for emergency workers.

5.2.1.8 • U.S. Agency for International Development

ORNL serves as a center of expertise on energy planning, policy development, and renewable energy applications for the U.S. Agency for International Development (AID) Office of Energy and Infrastructure in the Bureau of Research and Development. ORNL's activities include research; analysis; technical assistance; project development, implementation, and evaluation; and information dissemination. Efforts in energy planning and policy development emphasize energy efficiency improvement, environmental management, transportation systems, R&D roles, institution building, and technology cooperation. In renewable energy applications, ORNL emphasizes biomass energy systems and rural/decentralized applications. ORNL also supports programmatic activities in other AID components.

5.2.1.9 • U.S. Department of Transportation

The Department of Transportation provides funding to the Oak Ridge Transportation Technology Center (see Sect. 6.1.2) and supports the Center for Transportation Analysis (see Sect. 6.1.1.2), which covers all transportation modes. ORNL is assisting the Federal Highway Administration, the National Highway Traffic Safety Administration, the Office of Pipeline Safety, the Federal Transit Administration, the Federal Aviation Administration, and the Bureau of Transportation Statistics in research areas that include development of freight and passenger demand models; assessment of data quality and data consistency of highway statistics; development of data collection methods and advanced data management systems to improve data integrity and availability; analysis of nationwide surveys to address issues in current or future national transportation policies; development of methods to statistically link data sources to study intermodal traffic; and research on intelligent transportation systems. ORNL provides technical assessment of oil and gas pipeline systems throughout the United States for compliance with regulatory standards.

The Center for Transportation Analysis is engaged in a major initiative to provide technical support to the Federal Highway Administration on the Intelligent Transportation System. One aspect of this is a cooperative R&D agreement (CRADA) between ORNL and Scientific Atlanta, Inc., on the development of a portable automatic data acquisition system for crash avoidance research.

5.2.1.10 • U.S. Department of Commerce

ORNL is providing technical leadership in support of the Coastal Change Analysis Project (C-CAP). C-CAP is sponsored by the Coastal Ocean Program of the National Oceanic and Atmospheric Administration (NOAA) and administered through NOAA's National Marine Fisheries Service. ORNL's primary responsibility is to conduct R&D on land-cover monitoring in the coastal regions of the United States, in support of a national effort to monitor land cover gains and losses.

ORNL provides planning, technical coordination, and implementation of regional projects designed to employ the C-CAP protocols. Each project involves collaboration with a university, state government agency, or other regional organization. Technology transfer will be a key technical requirement in the collaborative efforts. Regional projects include Galveston Bay, the Louisiana coast, Tampa Bay, the South Carolina coast, the North Carolina coast, the Rhode Island coast, the St. Croix estuary, San Francisco Bay, the Columbia River estuary, the Alaska coast, and south Florida. ORNL processes satellite images and other data in support of these regional projects, develops improved methods and techniques for measuring spectral change, develops new methods and techniques for assessing accuracy in large spatial databases involving change over time, and is assisting in establishing an operational center for C-CAP at the Center for Coastal Ecosystem Health in Charleston, South Carolina.

5.2.1.11 • Other Federal Agencies

ORNL provides technical support to a variety of other federal agencies, including the U.S. Department of Agriculture (USDA), the U.S. Department of the Interior, the U.S. Department of State, and other agencies. The Laboratory anticipates collaborative work with the USDA, including the Agricultural Research Service, the U.S. Forest Service, and USDA research laboratories.

Support provided by the State Department for work performed for the International Atomic Energy Agency and the United Nations Educational, Scientific, and Cultural Organization (UNESCO) is expected to continue. ORNL is also assisting the U.S. country studies program in support of the Intergovernmental Panel on Climate Change, which is led by the State Department and supported by DOE, EPA, and AID. ORNL continues to assist the National Park Service in evaluating the environmental impact of extensions of the Foothills Parkway, adjacent to the Great Smoky Mountains National Park.

ORNL is assisting the Tennessee Valley Authority (TVA) in an assessment of the potential for biomass energy within the TVA power system. In addition, a major contract is in progress to conduct R&D for TVA in areas of mutual interest. These include the development of advanced diagnostics, advanced instrumentation and controls for TVA power plants, and techniques to improve the efficiency and reliability of TVA's transmission and distribution systems; assistance in improving end uses; and evaluation of the health effects of electromagnetic fields. TVA is a partner with ORNL and the University of Tennessee in the Joint Institute for Energy and Environment, described in Sect. 6.2.1.

Support is provided to the Bureau of Labor Statistics in artificial intelligence systems to provide estimates of consumer prices index and survey automation. Work is anticipated in support of the Office of National Drug Control Policy and its various support agencies.

ORNL provides support in environmental management of water resources to several other federal agencies. For example, ORNL staff serve as technical advisors to the Bureau of

Indian Affairs and the U.S. Army Corps of Engineers on environmental issues such as hydropower impacts on fish and wildlife and instream flow policies.

Under the sponsorship of the interagency Strategic Environmental Research and Development Program, ORNL staff have been involved in the formation of an interagency group including DOE, DOD, the Army, the Navy, the Agency for Toxic Substances and Disease Registry, and the EPA. The group's purpose is to improve the scientific methods and models for the performance and application of risk assessments.

5.2.2 • Nonfederal Organizations

ORNL performs research for and in collaboration with many nonfederal entities, both public and private. These efforts support DOE's mission to apply the resources of the national laboratories to issues and problems of national importance, especially in the areas of energy resources, environmental quality, and economic competitiveness.

5.2.2.1 • Electric Power Research Institute

The Electric Power Research Institute (EPRI) funds research at ORNL in areas related to the generation and efficient use of environmentally acceptable electric energy. The Laboratory expects to continue research in these areas for EPRI during the planning cycle.

Understanding the processes that control the atmosphere/surface exchange of mercury is the focus of an ORNL project that employs a number of proven field techniques, integrated with laboratory studies, to quantify the deposition and emission of mercury in forests and surface waters. The work is a joint effort involving ORNL, the National Oceanographic and Atmospheric Administration, and the Swedish Environmental Research Institute.

A program on compensatory mechanisms in fish populations has the overall objective of improved predictions of fish population response to disturbance. This program complements ORNL's work for DOE's Hydroelectric Program.

EPRI continues to fund research at ORNL in areas related to the efficient use of electric energy. An efficiency research project now under way is testing full-size ice storage systems for cooling commercial buildings.

ORNL's expertise in biomass energy is being applied to analyzing the potential of biomass feedstock for electric power plants. Interaction with the ORNL Biofuels Feedstock Development Program is expected to increase.

EPRI is co-funding the development and demonstration at ORNL of intelligent control systems for nuclear power plants (see Sect. 5.1.2.3). This includes such topics as validation and verification guidelines for software used in digital nuclear plant control systems and development of portable software that runs on a variety of hardware platforms.

ORNL carries out technology development for EPRI in the area of high-temperature structural design methods and fracture assessment procedures for advanced reactors and other high-temperature power plant components. In these activities, ORNL serves as EPRI's R&D arm in collaborative studies between EPRI, the Central Research Institute for Electric Power Industry in Japan, and the Central Electricity Generating Board in the United Kingdom. Results of these joint studies help to meet identified needs in DOE's reactor programs.

Assessment of the role of volatile salts (e.g., ammonium chloride) in the carryover of corrosive species in steam generator circuits has been limited by a lack of data and predictive models. Data obtained at ORNL are being incorporated into broader thermodynamic models.

EPRI also funds research at ORNL in the application of chaos theory to diagnosis and control of power generation systems. Recent activities have focused on characterization of fluidized bed combustion hydrodynamics and the development of data analysis algorithms for extracting nonlinear information from fluidized bed measurements. As part of this activity, ORNL has developed a close collaboration with the Technical University of Delft in the Netherlands and with Babcock and Wilcox (B&W), a major U.S. boiler manufacturer. It is anticipated that EPRI-sponsored fluidized bed research will continue, augmented by a major new thrust in the application of chaos to analyzing and controlling boiler flame dynamics, especially in regard to emission reduction.

Associated with EPRI research is work funded by the B&W Owners Group to develop an improved control system for currently operating B&W reactors. The project objectives are identification, documentation, and resolution of problem areas in the current control system; development of the optimum system configuration; exploration of technological improvements in control design methods; and provision of features that meet the expanded scope of control for the new control system. ORNL's project is a control algorithm that will be implemented by the B&W Owners Group on new digital control hardware.

5.2.2.2 • American Petroleum Institute

The American Petroleum Institute supports research at ORNL to evaluate the pharmacokinetics and pharmacodynamics of benzene in humans, with the aim of providing a better estimate of the risk of developing leukemia following exposure to low doses of benzene.

5.2.2.3 • Other Nonfederal Organizations

Private industry has joined with ORNL through CRADAs, licensing agreements, user agreements, and other mechanisms. ORNL also interacts with many other nonfederal entities, including

- Battelle Laboratories,
- SEMATECH,
- EG&G Energy Measurements, Inc.,
- the General Electric Company,
- the Florida Institute of Phosphate Research,
- the Metropolitan Edison/General Public Utility,
- the Pacific Power and Light Company,
- the Northwest Power Planning Council,
- the Soap and Detergent Association,
- the states of California, Virginia, and Alaska,
- the Canadian Atomic Energy Commission,
- the Federal Republic of Germany Umweltbunesamt,
- the Japan Atomic Energy Research Institute,
- the Korea Atomic Energy Research Institute,
- the National Institute of Radiation Protection of Sweden,
- the United Kingdom Atomic Energy Agency,
- the International Atomic Energy Agency,
- the National Geographic Society,
- the Center for Indoor Air Research,

- the Gas Research Institute, and
- Oak Ridge Associated Universities.

5.3 • Laboratory Directed Research and Development

The principal objective of the ORNL Laboratory Directed Research and Development (LDRD) Program is to provide financial support for innovative R&D ideas that, while within the general mission of the Laboratory, have no direct programmatic funding. Such ideas can and do lead to productive new technical directions for the Laboratory, DOE, and the nation. The program operates under the authority of DOE Order 5000.4A, "Laboratory Directed Research and Development" (April 9, 1992). It is funded by DOE through an overhead charge to all other Laboratory programs. All LDRD project funding requires the approval and authorization of the Laboratory director.

The LDRD Program comprises two major activities: the Seed Money Fund and the Director's R&D Fund. The Seed Money Fund is a continuation of the original ORNL Seed Money Program initiated in 1974; the Director's R&D Fund was added in 1983. The FY 1996 budget was $13.8 million; $3.3 million was allocated for the Seed Money Fund, and $10.5 million was allocated for the Director's R&D Fund (including $300,000 for capital equipment). The total budget authorized for LDRD amounts to less than 3% of the total operating budget for ORNL. Table 5.3 lists funding for FY 1995–FY 1998.

Proposals for Seed Money Fund projects are accepted directly from the Laboratory's scientific and technical staff at any time of the year, are peer reviewed, and are selected for funding with the assistance of a Proposal Review Committee composed of representative scientific and technical staff. (Requests for less than $15,000 can be approved by the LDRD Program Manager.) These nominally one-year projects are generally funded at no more than $100,000 each; the average project budget in FY 1995 was $78,374.

Director's R&D Fund proposals are solicited from the scientific and technical staff in June and are reviewed through line management; most are selected by the Laboratory's senior managers. These projects may continue for a maximum of three years, although most have durations of one to two years. The average FY 1995 budget for these projects was $173,198 including capital equipment; total budgets for all projects average about $425,000. From 5 to 10% of the Director's R&D Fund is allocated individually by the Laboratory associate directors.

Table 5.3
Laboratory Directed R&D funding by fiscal year
($ in millions—BA)

	1995[a]	1996[b]	1997[b]	1998[b]
Total funding	12.5	13.8	15.0	15.0

[a]Actual expenditures.
[b]Estimated.

For FY 1997, Director's R&D Fund proposals were solicited in two major categories: "Enhancing R&D Competencies" and "Gene and Protein Function." Additional information about these categories is presented in Sect. 6.3.1.

Providing multiple routes of access to LDRD funds maximizes the likelihood that novel ideas with scientific and technological merit will be recognized and supported. The selection process allows for the fact that new ideas are generally initiated by R&D staff, provides for peer review of proposals, and engages management in fostering projects that are oriented to the strategic directions of the Laboratory.

The LDRD Program is administratively part of the ORNL Office of Planning and Special Projects. The position of program manager generally rotates every two years among ORNL scientific and technical staff members. Additional descriptions of the program can be found in

- *Accomplishments of the Oak Ridge National Laboratory Seed Money Program,* DOE/ER-0274, U.S. DOE, 1986;
- *A Review of the Oak Ridge National Laboratory Seed Money Program,* DOE/ER-0319, U.S. DOE, 1987; and
- *Measuring Investment in R&D Excellence: A Study of Laboratory Directed Research and Development at the Nine DOE Multiprogram Laboratories,* DOE/ER-0361, U.S. DOE, December 1992.

The program operates efficiently and is held in high regard both internally and externally. For all divisions, the overall return of new work for the Laboratory is approximately three times the program's investment. The program provides the scientific and technical staff with morale-boosting incentives to be innovative. Many of the honors, awards, and new programs at the Laboratory have their origins in work supported by the LDRD Program.

The annual program plan for the LDRD Program, which is prepared and submitted to the DOE Office of Energy Research in accordance with DOE Order 5000.4A, serves to request LDRD funding for the Laboratory and to provide a general description of and justification for the LDRD program.

6 • Enterprise Activities

In addition to research and development (R&D) programs with direct support from a principal sponsor, described in Sect. 5, ORNL is engaged in a number of cross-cutting programs that support the missions of the U.S. Department of Energy (DOE). These include

- integrated R&D activities that cross disciplinary, programmatic, and organizational boundaries;
- science and technology partnerships that make ORNL's resources available to industry, universities, and other federal agencies through collaborative programs, user facilities, technology transfer, and education;
- activities through which the Laboratory develops new capabilities that are brought to bear on mission needs; and
- information and communication activities to ensure that the information needs of ORNL staff, DOE, and the public are met.

6.1 • Integrated R&D

ORNL's institutional competency in R&D integration and partnerships is exhibited in its ability to develop centers and programs that focus and leverage DOE resources. While some of these activities can be "located" within a specific R&D competency, most cut across several competencies. Some take advantage of the range of capabilities available at DOE's Oak Ridge facilities (the "Oak Ridge complex"). Many involve teaming with other DOE national laboratories, and others offer the potential for interlaboratory collaboration.

6.1.1 • ORNL Activities

6.1.1.1 • Laboratory Programs

Integrating Activities of ORNL Energy Programs

ORNL has the largest and most broadly based set of in-house energy programs among the DOE laboratories. These programs span fundamental research, applied work, and technology development; technical assistance; and management of energy-related information for DOE and a number of other sponsors, as described in Sect. 5.

Programs focus on energy efficiency and renewable energy, funded principally by the DOE Office of Energy Efficiency and Renewable Energy (DOE-EE); fission, with funding from the DOE Office of Nuclear Energy, Science and Technology (DOE-NE) and the Nuclear Regulatory Commission (NRC); fossil fuels, with funding from the DOE Office of Fossil Energy (DOE-FE); magnetic fusion, with funding from the Office of Fusion Energy Sciences within the DOE Office of Energy Research (DOE-ER); and transportation R&D,

with funding from DOE-EE, DOE's Office of Environment, Safety and Health, the Department of Defense (DOD), and the Department of Transportation (DOT). The work is underpinned by a substantial fundamental R&D effort supported by DOE-ER. Efforts are characterized by extensive collaboration within the Laboratory, with other DOE laboratories, with academia, with industry, and with other nations.

The breadth and depth of the ORNL capabilities, complemented by the wide range of collaborations, allow the Laboratory to play a leading role in making important, cross-cutting contributions to the energy area. Recent and ongoing examples include

- interdisciplinary research that links the physical, engineering, economic, and social sciences to provide insights for planning and policy decisions related to major energy and environmental issues of national and global concern;
- leadership in the analysis of the environmental externalities associated with energy production;
- development of frameworks for improved performance in technology development and deployment in industrialized and developing countries; and
- the preparation of the report *Energy Technology R&D: What Could Make a Difference?* in 1989, presently being updated as a multi-institution effort.

The energy programs of ORNL are committed to help in maximizing the output of the DOE system of laboratories, in a coordinated effort with academia, the private sector, and other U.S. government agencies in the U.S. and world energy arenas.

Neutron Sciences Programs

ORNL has a long and continuing competency in neutron science, dating from the 1940s. Although ORNL researchers occasionally make use of other facilities for specialized needs (e.g., pulsed slow neutron beams for scattering work, or larger irradiation volumes for materials testing), the Laboratory's competency in neutron science rests heavily on two in-house sources: the High Flux Isotope Reactor (HFIR) and the Oak Ridge Linear Accelerator (ORELA).

HFIR supports world-class research, production, and testing programs in neutron scattering, neutron activation analysis, isotope production, and material irradiation testing. ORELA now concentrates on nuclear astrophysics and basic neutron properties (e.g., neutron electric polarizability) research, but it is also available for other applications, such as target experiments for the proposed National Spallation Neutron Source (NSNS), and as a positron beam facility.

Other facilities supporting ORNL's broad neutron sciences programs include the Radioisotope Development Laboratory, the Transuranium Research Laboratory, the Radiochemical Engineering Development Center, and the Irradiated Fuels Examination Laboratory. The calutrons of the Isotope Enrichment Facility separate stable isotopes for use by outside researchers and can also make feedstock for radioisotope production. Neutron activation analysis capabilities are essential to a wide range of research (including medical and historical research) and operational (including pollutant detection and tracing) projects for customers inside and outside ORNL.

The common use of these facilities and capabilities by ORNL and non-ORNL workers integrates research program needs from DOE organizations [including DOE-ER's Office of Health and Environmental Research, Office of Fusion Energy Sciences, and the Chemical Sciences and Materials Sciences divisions in the Office of Basic Energy Sciences;

DOE-NE; and the Office of Defense Programs (DOE-DP)], universities, and private industry. ORNL is pursuing a major initiative, described in Sect. 4.1, to ensure that the Laboratory continues its stewardship of neutron science.

6.1.1.2 • Laboratory Centers

Center for Biotechnology

Biotechnology is an integrating science that emphasizes the development and application of biological approaches, or the use of engineering and computational capabilities, to meet national needs in health and environmental protection, biomedical applications, environmental remediation, pollution abatement, and energy production. ORNL is uniquely positioned to assume national leadership in this emerging field owing to its diversity of interactive disciplinary foundations (e.g., biology, biochemistry, molecular biology, computational sciences, chemistry, ecology, bioengineering, and biophysics) and its R&D competency in biological and environmental science and technology.

Among the DOE national laboratories, ORNL has the single largest biotechnology effort. ORNL is also is the only national laboratory with major efforts in all three areas of biotechnology research: biomedical, bioprocessing, and environmental. Its capabilities and activities are the broadest among the national laboratories.

The ORNL Center for Biotechnology provides a coordinated focus for ORNL's biotechnology effort, integrating activities across 14 ORNL divisions and forming partnerships with other institutions, both private and public, throughout the world. DOE sponsors include DOE-EE, DOE-ER, DOE-FE, DOE-DP, and the Office of Environmental Management (DOE-EM).

Other federal agencies sponsoring biotechnology R&D at ORNL include DOD (all branches, including the National Guard), the Environmental Protection Agency, the National Institutes of Health, and the National Science Foundation. Cooperative R&D agreements extend ORNL expertise in biotechnology to 14 private-sector partners. Research activities extend from the Arctic Ocean to the Antarctic and include the Human Genome Program, the development of systems for producing fuels and chemicals from renewable feedstocks, and the bioremediation of contaminated sites.

Biomedical research is directed at providing an improved understanding of the human genome and better, less expensive medical technology. In genome research, ORNL's mouse genome studies provide models for understanding the human genome in terms of genome structure/function relationships and the basis for hereditary human diseases, such as polycystic kidney disease and sickle-cell anemia. Cryopreservation of sperm and embryos of mice allows valuable mutants to be preserved at low cost. With GRAIL, ORNL's Gene Recognition and Analysis Internet Link program, researchers anywhere can rapidly obtain predictions of the positions of introns and exons in raw DNA sequences by electronic mail, with a comparison of assembled exon sequences to sequences in the international databases. A strong structural biology program focuses on genome analysis using X-ray and neutron diffraction, mass spectrometry, scanning probe microscopy, and electron microscopy with holographic analysis. Protein engineering of human growth factors is determining the essential structural features for activity. In ORNL's nuclear medicine program, radiopharmaceuticals are designed and synthesized to deliver radioactive isotopes to targeted disease sites in humans to make tumor inactivation and diagnosis as specific as possible. The development of biosensors is producing new diagnostic equipment, such as an award-winning endoscope that

uses laser light to identify cancerous regions of the human esophagus with near 100% reliability, with efforts to extend this technique to other organs.

Bioprocessing uses living organisms or their viable fractions to produce new products; it is the critical link between fundamental science and innovative industrial application. Industrial applications of bioprocessing have had an impact in fossil energy, chemical processing, fermentation, environmental control technology, agriculture, and biomedical advances. The Bioprocessing Research and Development Center (BRDC) supports ORNL's expanding role in this area. A major emphasis is on bioprocessing systems that can economically produce fuels and chemicals from renewable feedstocks, including the use of appropriate waste materials. Other BRDC activities include the development of techniques for less energy-intensive bioprocessing of petroleum and coal and systems for the degradation or removal of process pollutants. Solar-energy-driven bioprocesses are being studied for production of fuels and chemicals via routes such as carbon dioxide use and recycling.

Research in environmental biotechnology combines the principles and methods of molecular biology with those of microbial and physiological ecology to address significant environmental issues. The development of biomarkers—detectable biological responses of organisms inhabiting contaminated environments—is being used to assess changes in water quality associated with remedial actions. Because biomarkers provide an integrated measure of bioavailable contaminants and can indicate exposure to rapidly metabolized compounds, they provide information not available from chemical analyses of media or body burdens.

Techniques developed in molecular biology are also applied to bioremediation. Collaborative research with industry includes a project with General Motors to evaluate bioremediation of contaminated groundwater at a site in Michigan and a project with REMTECH to develop a technology for the efficient biodegradation of glycol-based wastes, such as antifreeze and deicing compounds.

The development of a virtual biotechnology laboratory, representing the integrated capabilities of the DOE national laboratories, is outlined in Sect. 6.1.3.3. DOE's new National and Accelerated Bioremediation Research (NABIR) program, which is designed to develop knowledge that will support environmental restoration of DOE facilities, also affords opportunities for integrated R&D, as described in Sect. 6.1.3.4.

Center for Computational Sciences

The ORNL Center for Computational Sciences (CCS), which includes one of the world's most powerful computing centers, is a focus for high-performance computing projects and collaborations with academia, industry, and other federal laboratories, including the major Laboratory initiative in distributed computing described in Sect. 4.3. Through these efforts, the CCS extends its impact far beyond the boundaries of the Oak Ridge campus.

The primary CCS responsibility is the success of the major DOE-ER Grand Challenge projects dependent on CCS resources (e.g., computing, storage and access, and code development). Two of these projects, Materials Simulation and Groundwater Transport and Remediation, are focused at ORNL; others—including Quantum Chromodynamics, Quantum Structure of Matter, Numerical Tokamak, and Computational Chemistry—involve teams from across the country. The CCS also provides expertise and extensive computational resources to DOE's Computer Hardware, Advanced Mathematics, and Model Physics (CHAMMP) program. In addition, resources are provided to the National Energy Research

Supercomputer Center (NERSC); to many other organizations or programs involved in systems evaluation, benchmarking, and exploratory studies with parallel codes; and to ORNL.

Of primary importance in a modern high-performance computational environment is a high-performance storage and access system. The CCS has become a leader in this realm, with a hierarchical storage system whose capacity is in the range of 100 terabytes. The CCS is also one of the primary developers of the next-generation High-Performance Storage System (HPSS), collaborating with other DOE laboratories and IBM Government Systems to develop this very-high-performance storage software system (see Sect. 5.1.3.1). The CCS is working closely with Sandia National Laboratories to link the two huge Intel Paragon computers at the two sites, via high-speed asynchronous transfer mode networks, into a metacomputer for the solution of scientific and technical problems that are too large for any current single computing platform.

Industrial participation is an important component of the CCS. The Computational Center for Industrial Innovation (CCII), a designated user facility, is the ORNL focal point for cooperative computational projects with industry. Industrial opportunities include extended-term, large-scale cooperative projects and initiation forays with organizations exploring new territory. A leading-edge visualization environment is a key component of the CCII, as it is for most of the CCS projects.

Center for Engineering Systems Advanced Research

The strategic goal of the ORNL Center for Engineering Systems Advanced Research (CESAR) is to expand, through fundamental and applied research, the Laboratory's capabilities and leadership in advanced computational methods for distributed nonlinear systems. The current emphasis is on cooperating autonomous systems (e.g., mobile intelligent robots) and on nonlinear science applications (e.g., seismic analysis). Research objectives are chosen to address the technology-base requirements for DOE missions that rely on the use of intelligent systems or require the solution of Grand Challenge problems, where the development of revolutionary algorithms for innovative use of high-performance computing technology plays a critical role.

The Engineering Research Program of DOE's Office of Basic Energy Sciences is CESAR's primary sponsor. Additional support is provided by other DOE offices and programs (including the Office of Nonproliferation and National Security), the Department of Defense (including the Office of Naval Research, the Ballistic Missile Defense Organization, and the Naval Surface Warfare Center), and the intelligence community.

Computational nonlinear science involves the development of analytical techniques and computational tools to gain understanding of spatiotemporal dynamical processes characterized by (potentially unknown) nonlinear mathematical models. Research in this area has been an intrinsic part of CESAR's activities (e.g., neural networks) for several years and has been recognized by the scientific community as an important priority for energy engineering research. CESAR's goal is to set forth a general methodology that cuts across many application domains and fosters new directions in the more traditional approaches to intelligent systems. Technology elements include neural networks (finite sample learning, dynamic pattern recognition, hyperspectral sensors, multisensor fusion), global optimization, innovative methods and algorithms for efficiently solving linear and nonlinear partial differential equations on massively parallel supercomputers (e.g., time-parallel algorithms), inverse problems, and prediction of deterministic nonlinear dynamics. Monitoring (e.g., environment,

chemical plants), geophysical information processing (e.g., oil exploration), and modeling of material processes are representative DOE areas of interest. Non-DOE applications currently focus on remote sensing and imagery exploitation.

In the area of cooperating autonomous systems, CESAR's activities emphasize intelligent systems that integrate perception, reasoning, and action to perform cooperative tasks under circumstances that are insufficiently known or that dynamically change during task execution. The CESAR cooperative robotics testbed is a unique, state-of-the-art experimental facility for robotics that includes five research robots equipped with an extensive variety of high-performance sensors and autonomous computation and communications capabilities. This CESAR laboratory provides an excellent platform for experimental and theoretical research in cooperating intelligent machines that is unmatched in the United States.

CESAR R&D activities continue to yield significant results in the technology transfer arena. Several major oil producers and seismic exploration companies (Amoco, CogniSeis, Chevron, Shell, and Unocal) have expressed strong interest in CESAR technologies (specifically, neural networks and global optimization). The Demand-Activated Manufacturing Architecture (DAMA) project of the American Textile Partnership (AMTEX) uses CESAR-developed data fusion and neural network methods for forecasting. Further significant liaisons, transfer of research results, and interactions with applied programs include work with the DOE-EM robotics program, the Oak Ridge Centers for Manufacturing Technologies, and the Oak Ridge Transportation Technology Center. The Alliance for the Advancement of Robotics Technology, discussed in Sect. 6.1.3, will ease access to CESAR expertise for industry, universities, and other federal agencies.

CESAR continues to play a major role as a hands-on basic research training center. Participants are supported by faculty research programs, DOE fellowships, undergraduate and graduate programs such as the Science and Engineering Research Semester, and minority programs. Links with leading universities and laboratories, both nationally (e.g., interagency agreement with NASA–Caltech/Jet Propulsion Laboratory) and internationally, further expand CESAR's outreach. This is illustrated by the large number of national and international visitors, contacts, and ongoing collaborative efforts.

Several CESAR scientists serve as members of the editorial boards of leading journals, conference chairpersons, and invited members of international program and technical committees. Furthermore, publications in peer-reviewed archival journals, books, and refereed conference proceedings, as well as patents and R&D 100 awards, document CESAR's research results.

In summary, CESAR is uniquely positioned to serve the needs of the scientific and engineering community. Drawing on a very successful growth and organic development over the last ten years, CESAR has matured into a center that is sought for its unique capabilities and expertise.

Center for Global Environmental Studies

The exploration of global environmental issues is of critical importance in determining directions for the future. These issues are complex, interwoven, and global in scale; they include greenhouse gases, climate change, ozone breakdown, deforestation and desertification, resource depletion, the spread of pollution, and the development of science and technology to support sustainable development. The ORNL Center for Global Environmental Studies (CGES) provides an interdisciplinary base for exploring these issues through a

diverse program that is tied to the U.S. Global Climate Research Program. The CGES focuses the Laboratory's unique capabilities in working toward three main goals:

- improving the understanding of the global-scale workings of environments in air, on land, and in water;
- developing capabilities for anticipating the long-term, large-scale effects of human actions on the biosphere; and
- identifying appropriate options for technological and societal responses.

Our approach includes a large-scale, long-term view; a commitment to collaboration among institutions and among disciplines; and a continual emphasis on realistic policy. The unifying framework for these efforts is global systems analysis: the development of increasingly sophisticated mathematical and conceptual models reflecting the dynamic interactions of subsystems (e.g., global vegetation, human cultures and behaviors) and earth systems (e.g., atmospheric chemistry, ocean composition and circulation) and the links between air, land, and sea. The long-term goal is to develop analytical tools that include the effects of demographics, land-use patterns, economics, ecological relationships, water resources, and other factors influencing the environment.

The CGES is uniquely positioned to serve the needs of federal agencies and international efforts and to make a significant contribution to our understanding of the biosphere. Expected future contributions include improved understanding of the terrestrial component of the global carbon cycle, improved understanding of the effects of elevated CO_2 concentrations on plants, improvements in the performance and predictability of global climate models, effective models for integrated assessments, full exploitation of industrial ecology approaches to support domestic and international sustainable economic development, improvements in utilization of water resources, and improved quality and diversity of global environmental databases.

Center for Transportation Analysis

The Center for Transportation Analysis (CTA) conducts innovative, cost-effective R&D on transportation energy and environmental issues, national transportation planning and policy, military transportation and logistics, and transportation systems engineering. The CTA focuses on multimodal national and international transportation systems. Staff members develop and apply advanced computational techniques, analytical methods, and information resources to improve economic and energy efficiency, environmental quality, mobility, national security, and public safety.

A mixture of technical and scientific backgrounds and diverse project sponsorship strengthens CTA's interdisciplinary approach to problem solving. Staff expertise includes transportation engineering, transportation geography, transportation economics, operations research, computation and computer science, and other physical and social sciences. CTA enjoys a close association with the worldwide academic community, with special support from the University of Tennessee and Vanderbilt University. Work is performed for DOE and other federal agencies, most notably the Department of Transportation (DOT) Federal Highway Administration (FHWA; see Sect. 5.2.1.9). Within FHWA, several offices involved in the Intelligent Transportation System program sponsor a significant amount of CTA research. Other sponsors include the DOT Bureau of Transportation Statistics; the U.S. Environmental Protection Agency; the Department of Commerce; Bureau of the Census; and, in DOD, the U.S. Air Force Air Mobility Command, the U.S. Transportation Command, and

the Military Traffic Management Command. The CTA is integrated into the Oak Ridge Transportation Technology Center, described in Sect. 6.1.2.

6.1.1.3 • Laboratory Capabilities

Isotope Production

Radioisotopes are vital to the economy and to U.S. international competitiveness: economic benefits are over $250 billion annually, including millions of jobs.

ORNL, which played a pioneering role in the development, production, and use of radioisotopes and stable isotopes, continues to work toward ensuring a reliable supply of essential isotope products, giving preference to supporting medical and research applications, and to fully meeting the needs of isotope users and stakeholders. This work supports the DOE National Isotope Strategy and its supporting legislation, as well as other critical national needs. A vital ORNL isotopes capability is a critical component of future U.S. R&D and production activities in support of beneficial uses of isotopes.

The technical capability for beneficial uses of isotopes at ORNL consists of (1) R&D on isotope materials and potential applications; (2) development of isotope production processes and products; (3) specialty production of custom isotopes and isotope product materials for research in medicine, nutrition, biology, geology, physics, chemistry, and environmental sciences; (4) production of isotope products for crucial national needs; and (5) technology transfer of isotope production processes and products to commercial industries. The isotopes capability is synergistic with ORNL's strengths in neutron sciences, materials research, and separations science.

ORNL facilities, such as the calutrons of the Isotope Enrichment Facility (IEF), the High Flux Isotope Reactor (HFIR), and the Radiochemical Engineering Development Center (REDC), have some unique capabilities for isotope production. Other hot cell and laboratory facilities, including the Radioisotope Development Laboratory in Building 3047, are needed for recovery and purification of radioisotopes or for product fabrication. Various laboratory facilities and specialized equipment are essential for preparation of chemical and physical forms of the isotope products for specialized uses. Special-form targets are often fabricated using metallurgical, ceramic, and high-vacuum processing techniques for subsequent production of radioisotopes in accelerators and reactors.

Programmatic activities, described in Sect. 5.1, include research in support of new applications for nuclear medicine, basic research on the transuranium elements, ^{192}Ir production, stable isotope enrichment, and transuranium element production. Transplutonium element isotopes are produced in the HFIR and the REDC through the National Heavy Element Program. The REDC is the production and distribution center for transplutonium element isotopes (e.g., ^{252}Cf) in the United States and the western world.

Work is done in collaboration with other national laboratories and with various universities and research institutions in the United States and abroad. The capabilities of ORNL facilities and personnel are often used to develop, demonstrate, and transfer technology to industry and to other government programs. New isotope products and methods are developed and transferred to industry (e.g., through the cooperative R&D agreement process) when they are commercially profitable. Various new products are evaluated in collaborative programs with over 20 medical cooperative programs at clinics, universities, and other research institutions in the United States, Europe, Australia, and Asia.

Californium-252 neutron sources are supplied to more than 30 universities for teaching and research as part of the University Loan Program. Enriched stable isotopes are supplied to many universities from the Research Materials Collection, an inventory of over 200 different isotopes that is maintained for research support purposes. In addition, research collaborations with universities are frequently carried out by many of ORNL's isotope technology programs.

These programs have a combined funding level of about $25 million per year. Estimated revenues from sales of ORNL-produced isotopes and technical services were approximately $12 million in FY 1996. All revenues are returned to the national Isotope Production and Distribution Program, and all funds are appropriated from the DOE sponsors.

Political changes and the U.S. budget deficit threaten the development of vital new facilities. Maintaining and upgrading the existing ORNL infrastructure (the HFIR, hot cell and laboratory facilities, and the IEF) is critical to ensuring the capability for isotope production until replacement facilities are available. The Oak Ridge Center for Isotope Technologies, a national activity for pursuing technology related to stable and radioactive isotopes, is proposed in Sect. 6.1.3.5.

Separations and Chemical Processing

Oak Ridge expertise in separations and chemical processing was initially developed in response to the challenge of purifying crude uranium and separating isotopes. Work based on separations and chemical processing has continued throughout the Laboratory's history. Present programs range from the most fundamental research to demonstration projects.

Separations science draws on expertise in solvent extraction, inorganic membranes, adsorption, ion exchange, field-enhanced separations, and dilute solution chemistry. The chemical processing capabilities of ORNL include analysis of thermophysical properties, computational chemistry, fluid mechanics, pilot-scale operations, process modeling, and life-cycle analysis. Other capabilities include equipment for testing most separations and chemical processes, extensive analytical expertise, and advanced capabilities in process control and monitoring. ORNL divisions involved include the Chemical Technology, Chemical and Analytical Sciences, Engineering Technology, Environmental Sciences, Instrumentation and Controls, and Robotics and Process Systems divisions.

The ORNL program for separations and chemical processing supports DOE programs in the Offices of Energy Research; Nuclear Energy, Science and Technology; Environmental Management; Energy Efficiency and Renewable Energy; and Fossil Energy. Its participants, about 400 persons, hold national offices in related professional societies, serve on national committees that advise government agencies in these areas (principally for DOE), operate a major conference in chemical separations, and serve as editors and on the editorial boards of important journals in separations.

The following initiative proposes the development of a center for extending these capabilities to the industrial sector.

Initiative

Center for Separations and Chemical Processing

This initiative will extend ORNL's capabilities in separations science to applications of benefit to industry by establishing a Center for Separations and Chemical Processing (CSCP) at ORNL. This center will provide an integrated program and a user center with capabilities to support the U.S. chemical industry in the fields of separations and chemical processing.

Separations and chemical processing problems represent a large portion of the technical challenges facing process industries worldwide. At the production end, increasingly stringent requirements for purity are being placed on manufacturers of chemicals, pharmaceuticals, food, and materials. At the waste control end, the recovery of chemicals is environmentally and economically necessary. Other considerations include the need for accurate design and pilot plant data, which are essential to workable designs. The availability of good data also minimizes engineered overcompensation and ensures more efficient use of resources and energy. Thus, the process industries face many problems and challenges that are concerns at ORNL.

The separations and chemical processing expertise available at ORNL represents a useful asset for private and public institutions that are addressing these problems and challenges. Industry has exhibited strong support, with joint research projects and cooperative R&D agreements in the emerging technologies of field-enhanced separations, thermophysical measurements, computational chemistry, computational chemical engineering, and life-cycle analysis.

A survey of potential industrial users shows strong interest in and support for a national laboratory center with separations and chemical processing capabilities. This interest results in part from the streamlining and reengineering of industrial R&D in the United States, which has eliminated a number of internal process engineering groups, and from the disappearance of chemical engineering data groups in the academic community as the professors managing the research retire. The survey of industries shows that firms are beginning to plan for obtaining the needed services.

The proposed CSCP will combine ORNL capabilities in separations science, chemical processing, and supporting areas. It will have two major functions.

First, the CSCP will coordinate programmatic projects related to the separations and chemical processing problems of industry and government. These include projects such as the Chemical Plant of the Future, the Refinery of the Future, and the Pulp and Paper initiative of the Office of Energy Efficiency and Renewable Energy; environmental programs on solving petroleum waste problems for the Office of Fossil Energy; and projects on thermodynamics and fluid mechanics for the Office of Basic Energy Sciences.

Second, the program will assist in establishing a user center for the measurement of chemical process engineering data. This Center for Chemical Processing Development will establish facilities to assist users in measuring thermophysical properties, making measurements on unit operations, carrying out pilot-scale studies, and instrumenting operations under harsh conditions. Expertise and facilities will also be available for computational chemistry, process modeling, and life-cycle analysis. These services will be available not only to the traditional large manufacturers but also, for the first time, to small businesses. The existence of pilot plants with unit operations

would make it possible to use the facilities as a training resource for universities and industrial operations.

The CSCP will bring together activities that represent the Chemical Technology, Chemical and Analytical Sciences, Engineering Technology, Environmental Sciences, Instrumentation and Controls, Metals and Ceramics, and Robotics and Process Systems divisions of ORNL. The location of the CSCP in Oak Ridge provides some unique advantages, and participation from other organizations across the Oak Ridge complex will be sought as part of the development of the CSCP.

Integrated Assessment

Integrated assessment is a process in which the scientific, technical, social, environmental, and economic inputs and consequences of a decision are evaluated to provide the information and analyses needed by policy makers and other decision makers to arrive at informed decisions on science and technology. For any problem, integrated assessment identifies the policy alternatives; analyzes the scientific, technical, social, environmental, and economic costs and benefits of each alternative; identifies the major sources of uncertainty; and provides some measure of the consequences of a wrong decision.

ORNL has a unique breadth of scientific, engineering, environmental, economic, and social science expertise to address the broad range of issues that arise in performing an integrated assessment, as well as extensive experience in using interdisciplinary teams to address a wide range of issues, from the generic relicensing of all commercial nuclear power plants in the United States to evaluating the safety, environmental, and health initiatives supporting U.S. research operations in Antarctica. The objective of ORNL's integrated assessment activities is to develop and implement assessment methodologies for conducting comprehensive, interdisciplinary assessments of global climate change.

ORNL provides planning support to several parts of DOE by providing assessments and analyses of research opportunities. Other examples of ORNL's integrated assessment capabilities include the vertical integration of research results into assessment and policy analysis under the National Acid Precipitation Assessment Program. ORNL activities in integrated assessment feed into the National Center for Environmental Decision-Making Research, sponsored by the National Science Foundation, in which ORNL is a partner through the Joint Institute for Energy and Environment (see Sect. 6.2.1).

ORNL is helping to focus the national integrated assessment programs by organizing and conducting a series of national and regional workshops that will identify national policy issues and the available frameworks and methodologies to address these issues. Approaches for regional ecological integrated assessments are also being developed through a separate series of workshops. A systems view is used in coordinating the interdisciplinary thrusts needed to fully understand the effects of global climate change on social systems and the environment. Reduced-form models that will combine appropriate social sciences with ecosystem theory are being explored, as are data availability and accessibility issues.

Surface Engineering and Coating Technology

Surface modification and coating technology play a crucial role in supporting DOE missions in energy resources. Surface modification and coatings can directly contribute to energy efficiency and drastically reduce energy consumption throughout product life cycles.

Surface modification technologies also serve to enhance the use of sustainable raw materials that are environmentally benign or that mitigate impacts. For example, beryllium plasma spraying is a leading candidate in containment/shielding fabrication for the International Thermonuclear Experimental Reactor and the National Ignition Facility. Intermetallics, special high-temperature alloys, composites, and other materials are all expected to be used in applications for energy production, efficiency, and use.

ORNL possesses a broad and diverse range of capabilities for surface modification and coating technologies, spanning many divisions and extending from advanced materials deposition technology to surface alteration via chemical, mechanical, and physical means. Skills and facilities, though technically diverse, share common qualities in their application to advanced materials development and in their extensive use in collaborations with the manufacturing sector.

The deposition of materials in coatings of varying thickness and the surface modification of substrates and coatings support a variety of activities in ORNL divisions and in the Oak Ridge Centers for Manufacturing Technology. These activities include plasma spraying, thin-film vapor-phase and plating deposition at both research and production-scale levels, and laser ablation (Engineering Technology Division); ion implantation and thin-film rechargeable batteries (Solid State Division); chemical vapor deposition, diamond coatings, and surface characterization and analysis (Metals and Ceramics Division); and plasma source ion implantation (Fusion Energy Division).

Advanced chemical and physical vapor deposition facilities at ORNL support activities ranging from thin-film batteries to fixation of unusual materials (including organics) on a variety of substrates. Technology for laser ablation of oxides is being developed for highly controllable deposition of complex advanced material. Surface cleaning techniques based on pellet injection technology, developed for fueling fusion experiments, are being applied to conventional industrial uses such as paint stripping. Ion implantation for surface toughening is being expanded with plasma sources that conform the ion species to the irregular shape of the target, improving distribution uniformity over less sophisticated line-of-sight methods. A full range of interdisciplinary surface characterization capabilities, including morphology and composition, chemical and mechanical properties, and machinability, is available.

ORNL capabilities in surface modification/engineering of materials are broad and may be best summarized as a coupling of experience in solving challenging problems and world-class materials expertise. The Laboratory's scientific and technological capabilities are applied to industrial and government needs to provide energy-efficient and environmentally sound alternatives, and the results of applied R&D are transferred to production use.

6.1.2 • Oak Ridge Activities

The DOE facilities in the Oak Ridge area—ORNL, the Oak Ridge K-25 Site, and the Oak Ridge Y-12 Plant, plus other organizations within Lockheed Martin Energy Systems, Inc. (LMES)—represent a unique resource. The "Oak Ridge complex" expertise in many areas of science and technology, manufacturing, and environmental management, combined with world-class facilities for applying these skills, adds up to a major asset for DOE and the nation.

6.1.2.1 • Advanced Instrumentation and Measurement Science

Capabilities in advanced instrumentation and measurement sciences, which are widely dispersed across the Oak Ridge complex, support nearly every scientific discipline and all of DOE's business lines. In a very real sense, all research missions at the Oak Ridge complex rely to some extent on the ability to develop advanced instrumentation and perform specialized measurements. The combination of scientific and engineering disciplines, unique facilities and equipment, and expertise at the Oak Ridge complex is unequaled elsewhere.

Work is under way to establish the Oak Ridge complex as a recognized leader in the innovation and application of advanced instrumentation and measurement systems for the benefit of DOE missions and U.S. industry. Input is being collected for a report that will serve as a "road map" for the development and coordination of the advanced instrumentation and measurement sciences capabilities by

- identifying the participants,
- defining the capabilities by technology area,
- defining a structure for using these capabilities effectively, and
- enumerating the benefits of a coherent organization for harnessing these diverse and varied resources.

The report will provide a readily available guide to the advanced instrumentation and measurement sciences capabilities of the Oak Ridge complex. It can be used in marketing these capabilities both internally and externally. To bring these capabilities to bear on a recognized industrial need, an initiative is proposed to develop an Intelligent Measurement Systems Laboratory.

Initiative

Intelligent Measurement Systems Laboratory

The instrument and measurement industry represents a large, diverse area of the economy. In 1990, according to U.S. Department of Commerce statistics, more than 10,000 U.S. companies, representing 949,000 employees, shipped almost $124 billion worth of instruments and related products. Most of these companies are small and have limited or no R&D capabilities.

Almost all major segments of the economy depend on measurements. Better measurement technology would allow the health care industry to decrease diagnostic costs and improve surgical support, the automotive industry to improve fuel efficiency and reduce pollution, and the agribusiness industry to carry out precision farming.

A critical requirement for enhancing U.S. manufacturing and process industry competitiveness is developing or improving affordable in-process measurement technology. Japanese businesses have repeatedly demonstrated enhancements in quality and reductions in the cost of manufacturing goods through the intensive application of such technologies. (In a 1987 study, DOE concluded that over $10 billion in energy costs could be saved in U.S. industry through improved sensor technology.)

The instrument and measurement industry is beginning to replace electromechanical sensing elements with silicon-based sensors, which transmit digital information instead of analog data. At present, 99% of the sensors in the field produce analog output, but this should change

quickly. Sensors that send digital output are easier to connect to computer data acquisition and data processing systems. These systems can incorporate computer algorithms and "if-then" rules, perform self-checking and self-calibrating, and autonomously make decisions on the basis of several measured parameters. These features may be thought of as "intelligence." Advances in the technology will improve these capabilities, resulting in more intelligent systems.

ORNL proposes to establish an Intelligent Measurement Systems Laboratory (IMSL) to assist industry in the assessment and use of intelligent measurement systems to provide energy efficiency, environmental compliance, and optimum control. As a user facility, the IMSL will provide design, simulation, prototyping, testing, and system integration facilities and technical resources requested by industry, universities, DOE, and other federal agencies. An industrial advisory board will keep the IMSL focused on the R&D needed for cost-effective higher intelligence in measurement systems. Development of these more intelligent systems will enhance the global competitiveness of U.S. industries, provide new manufacturing jobs for American workers, and further American education in measurement science.

Like the High Temperature Materials Laboratory, the IMSL will provide facilities and staff to industry and universities at no charge for nonproprietary R&D. Universities will provide graduate students, postdoctoral researchers, and collaborating professors. Industry will provide proposed projects and, in some cases, assigned personnel. Proprietary work that is aligned with the base R&D program will be performed at the expense of the industrial participant.

A measure of the value of the IMSL will be the amount of industry support that it attracts and maintains. We estimate that approximately 50 users per year will have agreements in place with IMSL within 5 years. Budget projections are shown in Table 6.1.

ORNL's Instrumentation and Controls Division provides a strong nucleus for a measurement science center. The Laboratory's research divisions will combine to provide a formidable interdisciplinary team that can address almost any sensor and measurement science problem or task. Strong synergy will exist between the IMSL and the Oak Ridge Centers for Manufacturing Technology.

Table 6.1
Budget projections by fiscal year for the Intelligent Measurement Systems Laboratory
($ in millions)

	1997	1998	1999	2000	2001	2002
DOE funding	0.6	1.5	3.0	5.0	10.0	10.0
Funding from other federal agencies	0.2	0.5	1.0	3.0	3.0	3.0
Total federal funding	0.8	2.0	4.0	8.0	13.0	13.0
Industry funding	1.0	2.0	2.5	5.0	6.0	6.0
Total funds	1.8	4.0	6.5	13.0	19.0	19.0
Distribution of funds						
Operating expense	1.8	3.4	5.0	7.0	10.0	10.0
Capital equipment	0.0	0.6	1.5	4.0	4.0	4.0
Construction	0.0	0.0	0.0	2.0	5.0	5.0

6.1.2.2 • Center for Applied Science and Technology in Law Enforcement

The Center for Applied Science and Technology in Law Enforcement (CASTLE), which is organizationally part of the LMES National Security Programs Office, provides a mechanism for applying ORNL expertise to needs in law enforcement. ORNL researchers have devised a command, control, and scheduling system that operates on a personal computer. The Atlanta Police Department used this system during the 1996 Olympic Summer Games to monitor resources, communicate management data, and make deployment decisions. The system, funded in part by the White House Office of National Drug Control Policy, is designed for an easy transition from command and control to high-end crime analysis and to use during events such as major earthquakes that could disrupt systems and destroy infrastructure.

6.1.2.3 • Oak Ridge Centers for Manufacturing Technology

Manufacturing is a major source of high-paying and highly skilled jobs that plays a central role in the national economy. The Oak Ridge Centers for Manufacturing Technology (ORCMT), a joint initiative of ORNL and the Oak Ridge Y-12 Plant, is a national industrial resource for applied research, development, deployment, prototyping, and education. The combination of ORNL's excellence in scientific R&D and Y-12's premier manufacturing capability is unmatched anywhere in the world. The ORCMT draws on the materials development, characterization, and processing expertise and the manufacturing and fabrication capabilities of Oak Ridge to improve American industrial competitiveness.

The centers that make up the ORCMT are organized in four core technology areas. ORNL contributions to the ORCMT include three especially significant areas: modeling, mechanics, and design; materials processing and applications development; and intelligent measurement systems.

Strategic alliances with the National Institute of Standards and Technology of the U.S. Department of Commerce, southeastern state economic development organizations, educational institutions, industrial societies, and industry consortia allow the ORCMT to complement existing activities. In FY 1995, the ORCMT stimulated over $172 million of private-sector impact in 46 states, with a strong emphasis on the southeastern United States. This represents a return on investment of more than 600% for the use of federal funds. Over a three-year period, the private-sector impact has been $335 million. The following initiative for applying the resources of the ORCMT to industry needs for resource efficiency and pollution prevention is proposed.

Initiative

Oak Ridge Energy and Environmentally Sustainable Manufacturing Center

Manufacturing industries use one-third of the energy consumed in the United States; 70% of this energy is used for heating and power production. Improving the energy efficiency of these industries and promoting environmentally conscious manufacturing would lower costs and improve economic productivity in this sector.

A manufacturing technology center addressing these concerns could become a

major natural resource, leading to technological innovations in product and process quality, improvements in performance, and competitive costs. The Oak Ridge Energy and Environmentally Sustainable Manufacturing Center, a collaborative effort with the Oak Ridge Centers for Manufacturing Technology (ORCMT), is proposed as a means of applying ORNL's scientific and technical capabilities to industrial and government manufacturing needs for energy-efficient, environmentally sustainable manufacturing technologies. The center's activities would

- emphasize developments that sharply reduce energy and environmental impacts while maximizing the use of sustainable materials;
- build integrated R&D alliances with the public and private sectors, including pilot-scale demonstrations;
- use private-public partnerships, including cooperative R&D agreements, to develop, demonstrate, and transfer product and process technologies; and
- maximize opportunities for customers to use the ORCMT and ORNL's unique facilities.

The proposed center would support a broad effort to establish and market ORNL as an innovative, cost-effective, responsive, and reliable partner in technology development.

6.1.2.4 • Modeling and Simulation Capabilities

There is a strong and growing national movement to increase the use of modeling and simulation in the development of processes and systems. Reliance on the expensive and inefficient method of several iterations of designing, building, and testing hardware is being reduced. Organizations responsible for implementing major systems are realizing the advantage of optimizing in a virtual sense before committing resources to a final product.

Across the Oak Ridge complex, many projects with a variety of sponsors are applying modeling and simulation, either in the course of R&D activities or for actual prototype and process evaluation and verification prior to building hardware. There are also centers of expertise within the complex where prototypical hardware is being built, integrated, and tested to verify and validate computer models. Collectively, these elements represent a strong capability (about $25 million in R&D funding for the current year) in support of DOE's businesses.

These work elements, and the growing pool of technical experts in this area, provide the impetus for development of a center of excellence for virtual prototyping.

Initiative

Virtual Prototyping Center

A Virtual Prototyping Center is proposed as a means of integrating and applying Oak Ridge complex capabilities in modeling and simulation for the development of processes and systems.

Virtual prototyping (VP) is the comprehensive application of modeling and simulation to each step in the development of a product. It provides a totally integrated, iterative approach that involves concept development, performance evaluation, operational testing, detailed design, and manufacturing processes in an interactive computer environment. VP is an enabling

technology that is expected to become increasingly useful as resources are collected and computing resources become less expensive. Many companies have already started this process, and the results have been promising. However, a complete VP plan could be implemented to tie together all of the development steps in one comprehensive system. This VP system could be a product for small businesses, a process for large businesses, or a user facility for all types of businesses.

The Virtual Prototyping Center would draw on the resources of at least five ORNL divisions (Robotics and Process Systems, Computer Science and Mathematics, Computational Physics and Engineering, Engineering Technology, and Metals and Ceramics) in three research directorates; on the Y-12 Plant's Development Division; and on the Central Engineering Services and Data Systems Research and Development organizations of Lockheed Martin Energy Systems, Inc. It would also span at least four major program areas: environmental management, transportation, ammunition logistics, and space and defense technology. This initiative would use the capabilities at existing centers (e.g., the Oak Ridge Centers for Manufacturing Technology, the Concurrent Engineering Center, the High Temperature Materials Laboratory, and the Center for Computational Sciences). Functional integration of these resources with a common vision and goals provides an expanded opportunity for synergy.

This initiative has several objectives. Of utmost importance is the integration and optimization of all VP elements currently in use at Oak Ridge. The Virtual Prototyping Center is envisioned as a comprehensive user facility, providing businesses with access to the resources and expertise located here—a capability that most businesses could not otherwise afford. The primary R&D focus would include

- modeling and simulation,
- virtual reality,
- computer applications,
- engineering and computational analysis,
- optimization (discrete and system-wide),
- supercomputing (use of massively parallel processors for virtual immersion applications),
- manufacturing technology,
- rapid prototyping, model verification, and validation, and
- materials (used in model properties as input to VP performance analyses).

This initiative also presents an opportunity to further enhance the capabilities available to industry through collaboration between the Oak Ridge complex and other DOE laboratories and facilities.

6.1.2.5 • Transportation R&D

The Oak Ridge Transportation Technology Center (ORTRAN) is responsible for leading in the development and expansion of transportation-related research activities for ORNL, the Oak Ridge Y-12 Plant, and the Oak Ridge K-25 site. These activities include projects conducted by the ORNL Energy Efficiency and Renewable Energy Program, the ORNL Center for Transportation Analysis, and the ORNL Center for Engineering Systems Advanced Research. ORTRAN promotes and supports new research activities focused on major transportation R&D issues related to energy, environment, and security for the nation and the world. Much of the work developed by ORTRAN involves universities and industry in cooperative R&D ventures.

ORTRAN's mission is to assure that the Oak Ridge complex develops a leadership role in transportation systems R&D and deployment, not only for DOE, but also for the Department of Transportation (DOT), the Department of Defense (DOD), and other agencies.

ORTRAN will forge partnerships within the Oak Ridge complex and with other public and private agencies and commercial industry. Program areas and goals are as follows.

- Partnerships and alliances: Promote and develop transportation-related activities that involve alliances or cooperative agreements with state governments, universities, and industry.
- Vehicle technologies: Integrate the transportation research activities sponsored by the DOE Office of Energy Efficiency and Renewable Energy (see Sect. 5.1.2.1) with other ORTRAN development areas.
- Intelligent transportation systems programs: Become the national leader in the development of DOT intelligent transportation systems activities related to simulation, modeling, and computing architecture, with the goal of applying modern computer and communications technologies to transportation systems, resulting in improved mobility, safety, air quality, and productivity. The term "intelligent" not only describes the underlying computer/communications technologies, but also applies to where and how these technologies are used.
- Planning and policy analysis: Lead in the development of projects related to transportation operations, economic analysis, policy studies, energy and environmental analysis, land use modeling, and systems analysis.
- Hazardous materials transportation: Develop new hazardous materials transportation operations, packaging, and environmental assessment research opportunities. Integrate the R&D activities of DOE's environmental management and transportation management functions with other ORTRAN R&D areas.
- Transportation environmental technologies: Develop new technologies related to mitigating the environmental impacts of transportation systems.
- Transportation manufacturing and infrastructure technologies: Develop advanced manufacturing and construction technologies that lead to fuel-efficient and less polluting vehicle technology and lower cost transportation infrastructure.
- Defense transportation: Lead in the development of new defense-related transportation technologies that improve overall rapid deployment capabilities and the utility and reliability of military vehicles.

6.1.3 • DOE National Laboratory System Activities

As an element of DOE's national laboratory system, ORNL works to combine its strengths with those of other national laboratories to focus the resources of this system on national needs. Strong capabilities can be created by teaming where activities are synergistic; costs can be reduced through integrated program development; customers will be better served by planned allocation of resources; and the integrated team approach can make the system of laboratories the best in the nation for specific technologies.

Work is in progress to establish centers that represent a form of the "virtual laboratory." The Alliance for the Advancement of Robotics Technology is already producing results. The Metals Processing Laboratory User Center at ORNL was designated a user facility in February 1996. Other centers, expected to become operational within the next

several months, are aimed at combining national laboratory capabilities in biotechnology and bioremediation and in isotope technologies.

ORNL is also participating in the development of "collaboratories"—the use of computing and communications technology for remote operation of user facilities—as another means of integrating the capabilities of the national laboratory system. A Laboratory Directed R&D project for the development of remote operation software is in progress. Remote operation of equipment in the ORNL High Temperature Materials Laboratory from San Diego, California, and other locations has been accomplished, and remote operation of equipment at the High Flux Isotope Reactor is planned. Remote collaboration via collaboratories will make ORNL's resources more accessible and affordable and will increase the utilization of Laboratory facilities.

6.1.3.1 • Alliance for the Advancement of Robotics Technology

ORNL performs research, development, demonstration, and application of remote systems, robotics, teleoperation, and related aspects of intelligent machines. These programs are interdisciplinary in nature and use the expertise of scientists and engineers from several research and support divisions of ORNL. Over 100 scientific and technical staff members are engaged in robotics R&D at ORNL. Program activities across the full spectrum of related technologies are under way for DOE, DOD, and other sponsors.

Across the DOE laboratory and production plant complex, over 350 scientific and technical staff members are dedicated to robotics research, development, demonstration, and application. This "distributed" capability represents a unique and highly important national resource. Eight DOE national laboratories and one production plant have formed a virtual center of excellence in robotics and remote systems technology for the DOE complex. The DOE Alliance for the Advancement of Robotics Technology (AART) will use the collective resources of its participants to develop and apply advanced robotics technology to reduce cost, improve productivity, enhance safety, and improve the effectiveness of DOE, industry, and other federal agencies. The concept, patterned on the model of the Technology Centers sponsored by the DOE Laboratory Directors, is now rapidly evolving. The purpose of the AART is to better organize the overall resources of the national laboratory system to meet DOE and national needs and to provide better access to the technology and capabilities of the participants by industry, academia, and other federal agencies.

6.1.3.2 • MPLUS: Metals Processing Laboratory User Center

ORNL has established the Metals Processing Laboratory User Center (MPLUS) to enhance the energy efficiency, environmental friendliness, and competitiveness of the U.S. metals industry. This industry is essential to maintaining the nation's technological strength in a global economy.

- Metals products form components in virtually all manufactured goods; thus, a technologically superior and competitive metals industry can propel the U.S. manufacturing industry into the next century.
- Metals producers are operating in a market that is steadily becoming more international.
- Producers in the metals industry must balance the need for continued technology investment with the risks of uncertainty in the technology.

Key tools in strengthening and enhancing the metals industry are the development and integration of improved materials and processes, accurate sensors, powerful and

user-friendly process design and control strategies, and material databases for process and product design, resulting in accelerated manufacturing cycles and products of higher quality and consistency. The national laboratories and other facilities of DOE possess broad capabilities for providing these tools.

Through an integrated development approach, advanced technologies and facilities can be applied for the benefit of both large and small businesses. MPLUS provides a single site with a dedicated staff and unique facilities for performing applied metals R&D; monitoring materials performance in applications and environments of interest; addressing environmental, safety, and health questions associated with processing; resolving end-use issues for alloys and processing technologies; and providing technical support for selection of metals, processing methods, and general fabrication considerations for many applications.

MPLUS will make use of user centers and alliances with industries and universities, and it will provide a basis for collaboration with major materials, manufacturing, and computational centers at ORNL and the Oak Ridge Y-12 Plant. The primary capabilities in MPLUS include

- metals processing,
- metals joining,
- metals characterization and properties, and
- metals process modeling.

Since the development of end-use products often requires incorporation not only of metals processing skills, but also of more generic materials issues, the extensive experience in the development and use of ceramics and composites represented by the capabilities available in Oak Ridge provides a major advantage of MPLUS.

The formation of MPLUS to assist industry and academia in solving metals processing issues has wide-ranging advantages and provides a unique national resource. In addition, by helping to satisfy customer requirements for price, quality, and delivery, MPLUS supports the goals of DOE's Office of Energy Efficiency and Renewable Energy and Office of Industrial Technologies (OIT). MPLUS will be an important part of OIT's efforts to meet the materials and processing needs of the "Industries of the Future."

Goals for MPLUS include enhancing company productivity and profitability by accelerating manufacturing cycles, improving product quality and consistency, and reducing waste. Increases in productivity and profitability should be achieved in conjunction with a reduced risk to the environment and should produce a safer, cleaner, and healthier working environment for employees. Ultimately, for the development effort to be effective, the technology must be affordable, and the program must include strategies for the commercialization of the developed technologies and for the dissemination and implementation of the technologies in all sectors of the metals industry. It must also provide for training, particularly in small companies, where the challenge of implementation of advanced technologies is likely to be the greatest.

6.1.3.3 • Interlaboratory Collaborations in Biotechnology

DOE is the principal source of funding for the three major areas of biotechnology: biomedicine, bioprocessing, and environmental research. The DOE national laboratories have an annual budget of over $340 million for biotechnology. Funding provided to the national laboratories from other federal agencies and the private sector approaches that from DOE, showing that the laboratories are an important national resource.

The ORNL Center for Biotechnology, described in Sect. 6.1.1.2, provides a mechanism for coordinating the Laboratory's resources in biotechnology with those of the other national laboratories. ORNL staff anticipate working with the other national laboratories, as part of the Biotechnology Interlaboratory Council, both to continue to develop interorganization collaboration and to work toward the development of a virtual center among the laboratories. The establishment of the council and the overall capabilities of the laboratories support this development.

6.1.3.4 • Natural and Accelerated Bioremediation Research Program

DOE's Natural and Accelerated Bioremediation Research (NABIR) program, which began in 1996, is designed to develop knowledge that will support environmental restoration of DOE's sites and facilities. Many of these sites are contaminated with complex mixtures of organic and radioactive chemicals. Because bioremediation uses microorganisms to degrade or transform hazardous contaminants to nontoxic constituents, it has the potential to be of great utility in the restoration of such sites.

ORNL has worked effectively with the Ernest Orlando Lawrence Berkeley National Laboratory, the Pacific Northwest National Laboratory, and other national laboratories to aid DOE's Office of Health and Environmental Research in the development and initial implementation of the NABIR Program Plan. ORNL plans to collaborate with other national laboratories to participate as a field research center for NABIR science. Collaborative efforts should allow NABIR to accomplish the necessary research at significant cost savings. Several field sites and controlled test field facilities are available at ORNL for NABIR field research. ORNL also plans to propose several major research projects to address the various scientific program elements of NABIR. We anticipate collaborative efforts with several national laboratories and universities.

6.1.3.5 • Oak Ridge Center for Isotope Technologies

The Oak Ridge Center for Isotope Technologies is proposed to coordinate the activities of a network of organizations and facilities. These activities include (1) performing R&D for new applications of isotopes or methods for producing them and transferring the developed technology, (2) specialty production of selected isotopes, and (3) routine production of selected isotopes to meet crucial national needs. The proposed center would integrate the efforts of the distributed participants in achieving their goals in these areas.

The network of organizations is extensive, crossing disciplinary, organizational, and geographical boundaries.

- A number of ORNL divisions (Chemical Technology, Chemical and Analytical Sciences, Health Sciences Research, Metals and Ceramics, and Research Reactors) are engaged in a range of activities, from research on new applications to specialty production of isotopes, as described in Sect. 6.1.1.3.
- Other national laboratories perform R&D related to isotopes or are involved in various stages of the production process for some isotopes (e.g., irradiating targets, processing isotopes).
- The radiopharmaceutical and medical community produces isotope products, conducts research on the use of isotopes, and employs isotopes in both diagnostic and therapeutic applications.

- The industrial sector can be divided into two categories:
  - producers, who irradiate targets, separate isotopes, incorporate isotopes into appropriate chemical compounds and forms, package isotopes, and sell isotopes, and
  - users, who employ isotopes in applications such as nondestructive analysis, process control, and sterilization of medical equipment.
- The federal government uses isotopes for national security (e.g., neutron radiography of aircraft) and scientific purposes (e.g., radioisotope power sources for satellites).
- Universities conduct research into the uses of isotopes and also produce some isotopes.
- Other nations have a significant interest in both the production and use of isotopes. Many isotopes (e.g., enriched stable isotopes) are produced in only a few places, while demand is ubiquitous, so international considerations are important.

Distributed throughout this network of organizations are many facilities for producing, studying, and using isotopes. The major types of facilities include stable isotope enrichment [e.g., mass separators (calutrons), thermal diffusion], target irradiation (e.g., reactors such as the High Flux Isotope Reactor, accelerators), radioisotope processing facilities (e.g., hot cells, the Radiochemical Engineering Development Center), and waste management facilities.

The Oak Ridge Center for Isotope Technologies will provide a focus for the particular activities related to the facilities and programs at ORNL, building on the Laboratory's outstanding capabilities and infrastructure for isotope production, while simultaneously taking a leadership role in networking with other organizations. The expected results are increased benefits from the use of isotopes with minimum cost impacts and supply interruptions while emphasizing participation of the private sector.

6.2 • Science and Technology Partnerships

ORNL is committed to collaboration with other federal agencies, industry, and universities. Institutional competencies in development and operation of national research facilities, R&D integration and partnerships, technology transfer, and science education provide a strong foundation for this commitment.

During the planning period, ORNL will continue to develop and draw on collaborative relationships that support DOE's missions. In particular, ORNL plans to increase its outreach efforts to small and medium-sized businesses. This effort will be focused on increasing awareness among these firms of cooperative research and technical assistance opportunities. These businesses are also good candidates for partnerships with the Laboratory under the Small Business Technology Transfer (STTR) Program, which is supported by DOE and other government agencies.

The ORNL Office of Science and Technology Partnerships (Partnership Office) is the focal point for cooperative interactions between ORNL and outside groups or individuals. Established in 1989 as the Office of Guest and User Interactions to facilitate collaborative R&D and access to the Laboratory, the Partnership Office serves as the primary contact for the designated user facilities at the Laboratory, provides assistance with the entrance and approval procedures for both domestic and foreign national assignments, negotiates user agreements, provides support services for research guests, and manages all programmatic and approval processes for cooperative R&D agreement (CRADA) activity at ORNL. A major responsibility of the Partnership Office is the management of the Energy Research

Laboratory Technology Research (ER-LTR) Program at ORNL (see Sect. 5.1.1.5). This program provides funding for many of ORNL's technology transfer activities.

Both the user program and CRADAs address the DOE mission to improve the economic competitiveness of U.S. industry by leveraging industrial and governmental resources to address industrial technology constraints and by more effective use of the DOE facilities by external groups.

6.2.1 • Collaborative Relationships

As the only national laboratory in the southeastern United States, ORNL places a strong emphasis on building collaborative relationships in this region, with particular emphasis on the University of Tennessee (UT). Other regional partners include the Tennessee Valley Authority, the Oak Ridge Institute for Science and Education, minority educational institutions, and area primary and secondary schools. The Oak Ridge Centers for Manufacturing Technology provide a mechanism for industry to access ORNL resources; many companies using this mechanism are also located in the southeastern United States.

A major effort is aimed at building new educational, training, and research partnerships—with other federal agencies, such as the Appalachian Regional Commission, the National Aeronautics and Space Administration, and the National Science Foundation; with schools, colleges, and universities; with educational consortia and museums, both regionally and nationally; and with private-sector institutions and organizations.

6.2.1.1 • University Partnerships

ORNL is involved in a number of research partnerships with universities, most of which also have a strong education component. Academic outreach is reflected as well in subcontracted R&D with university partners, which represents well over $20 million annually.

The Laboratory is working to establish stronger relationships with Tennessee's Centers of Excellence program for public higher education. This program supports 26 Centers of Excellence and a number of Chairs of Excellence, held by outstanding professors, at Tennessee Board of Regents institutions (6 universities, 14 two-year colleges, and 26 technology centers) and the UT campuses. Their purpose is to expand the state's research base, with the aim of increasing Tennessee's national and international stature and its ability to compete in the economic arena.

In March 1996, ORNL hosted a meeting of the Chairs of Excellence, the directors of the Centers of Excellence, and representatives of the Tennessee Board of Regents institutions. The main objective was to increase all participants' awareness of the diverse resources available to the state of Tennessee through the Centers of Excellence program and the Laboratory and to build relationships that will support the application of these scientific, academic, and intellectual resources to Tennessee's development.

The University of Tennessee

ORNL and UT are partners in the Science Alliance, the state's oldest and largest academic Center of Excellence. The Science Alliance sponsors the ORNL-UT Distinguished Scientist Program, which provides joint appointments to tenured positions at the University of Tennessee–Knoxville and research positions at ORNL, with program costs shared by the

two institutions. Joint institutes and graduate programs are an additional tool for combining the resources of these institutions for research and education. These include the Joint Institute for Molecular-Based Science and Engineering, established in FY 1996, and the Joint Institute for Energy and Environment, in which the Tennessee Valley Authority is also a partner.

The Joint Institute for Energy and Environment conducts research and other collaborative activities on critical topics related to energy and the environment. Skills and facilities from theoretical research through laboratory explorations to full-scale demonstration projects are combined with policy and social science expertise to address research topics such as the science and policy implications of climate change; the role of environmental education, training, and technology transfer in global economic development; domestic and international energy and environmental policy; and energy production and conservation. The National Center for Environmental Decision-Making Research, funded by the National Science Foundation, will develop new study methods, analysis tools, and processes to help government and private enterprise make use of scientific research in their environmental decision-making.

A memorandum of understanding with UT, Pellissippi State Technical Community College, and Roane State Community College was signed in April 1996. In addition, officials from ORNL and UT recently signed a memorandum of cooperation that will encourage joint research and help new technologies reach the market more quickly. The agreement will facilitate the creation of joint projects between ORNL and UT and the process of moving new technologies through the patent and licensing phases to, ultimately, the commercial stage.

Other Colleges and Universities

ORNL interacts extensively with minority educational institutions (MEIs) through mechanisms such as the DOE Science and Technology Alliance, the Waste Management Consortium, the National Consortium for Graduate Degrees for Minorities in Engineering, Inc. (GEMS), and the Advanced Industrial Concepts Materials Fellowship Program. ORNL also administers some 26 subcontracts with MEIs, representing commitments of more than $4.5 million.

ORNL's relationship with North Carolina State University was highlighted in a recent brochure issued by DOE's Office of Energy Research, "Who Uses the Energy Research Laboratories?"

6.2.1.2 • Industry Partnerships

ORNL supports DOE's efforts to improve the economic productivity of U.S. industry by leveraging industrial and government resources to address industrial problems and by encouraging more effective use of the DOE facilities by external groups.

The ORNL Office of Small and Minority Business Outreach serves as the focal point for projects involving minority businesses. One such project, sponsored by DOE's Office of Economic Impact and Diversity, is a workshop for minority colleges and universities. This intensive training program is aimed at enhancing business expertise and competitiveness in manufacturing by providing information that will enable minority businesses to enter high-performance manufacturing and develop technical self-sufficiency.

The Partnership Office will also have a focused effort to encourage more interaction with small businesses. Much of this activity is expected to occur in the technical assistance

area, where the ORNL Partnership Office will be working closely with the Lockheed Martin Energy Systems, Inc., Regional Assistance Program.

CRADAs

Cooperative partnerships with industry continue to be an attractive mechanism to afford access to the significant scientific resources and skills that exist here. Furthermore, the leveraging of research dollars through cost sharing is beneficial to both parties. At the end of FY 1995, ORNL's cumulative total for CRADAs was 232 (including joint ORNL/Y-12 projects), representing commitments of nearly $300 million split approximately half and half between federal monies and the private sector (see Fig. 6.1).

The ORNL CRADA portfolio encompasses many programs and technologies:

- Advanced materials, 34.4%
- Chemical, 3.3%
- Computing, 3.7%
- Diagnostics, 7.1%
- Environmental, 15,4%
- Instrumentation, 10%
- Manufacturing, 19.1%
- Other areas, 7.1%

Individual CRADAs are discussed in the appropriate programmatic areas in Sect. 5.

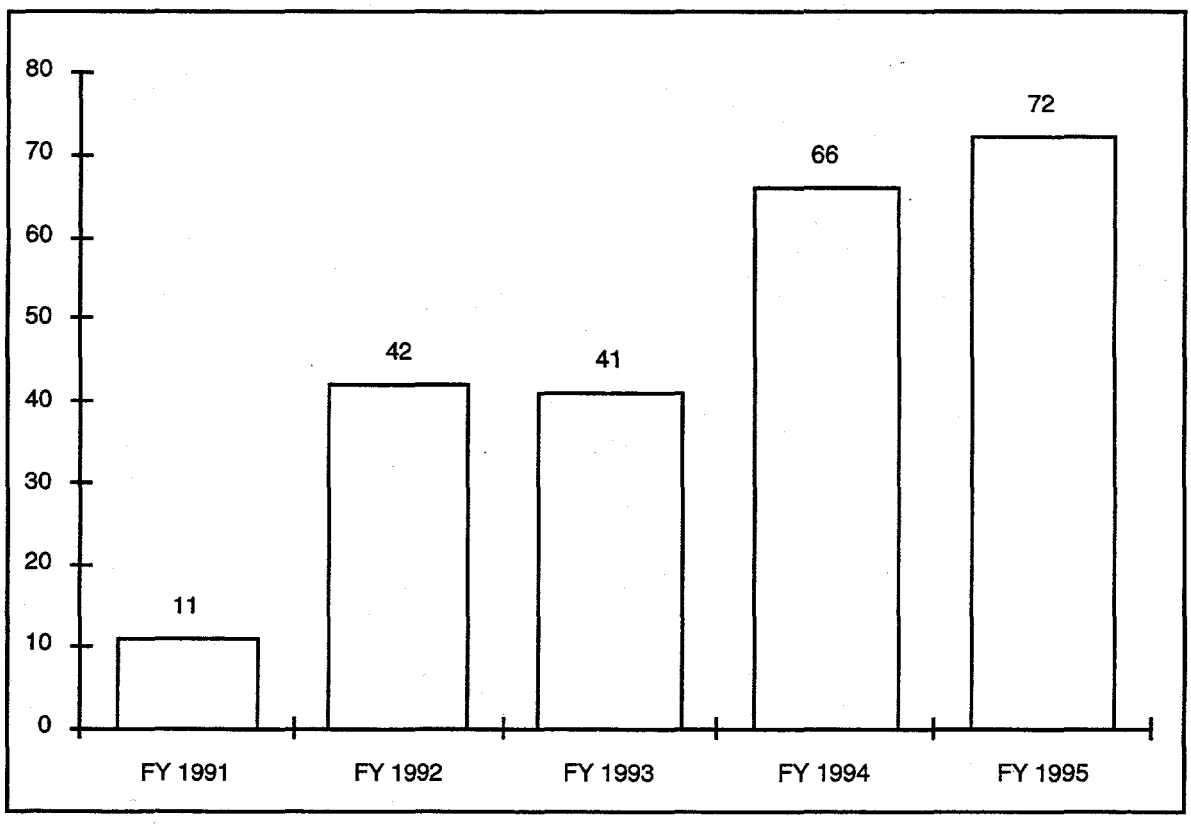


Figure 6.1
CRADAs established at ORNL from FY 1991 through FY 1995. Cumulative total of 232 includes joint ORNL/Y-12 CRADAs.

Industrial Consortia

The American Textile Partnership (AMTEX), a collaborative program involving ten DOE laboratories and the U.S. integrated textile industry, is engaging the technical capabilities of the laboratories in developing and deploying technologies that will increase the competitiveness of this industry. ORNL is currently involved in four AMTEX CRADAs. The Partnership for a New Generation of Vehicles also presents opportunities for cooperative projects that involve programs in the Offices of Energy Research (DOE-ER), Energy Efficiency and Renewable Energy (DOE-EE), and Defense Programs. ORNL is also pursuing the implementation of a partnership with the aluminum industry. Both the DOE-ER and the DOE-EE programs are working toward increasing opportunities for joint efforts with the aluminum companies.

6.2.2 • Guests and Users

6.2.2.1 • Guest Research

Guest scientists are a valuable component of ORNL's research staff. Their assignments, which range from two weeks to two years, broaden the Laboratory's base of expertise and support its mission of scientific cooperation and technology transfer. In FY 1995, the Partnership Office supported 4377 assignments of scientists and engineers from universities, industries, and other federal institutions. Of this number, 1217 were industrial guests. Guest statistics for the past three years are presented in Appendix A (Table A.1).

6.2.2.2 • User Facilities

Educational institutions and industries make extensive use of ORNL's 14 designated user facilities to carry out R&D for educational purposes and to develop new products and processes. The Laboratory's strong programmatic emphasis on energy efficiency, fossil fuels, advanced computing, environmental science, superconductivity, and defense technologies provides a firm basis for establishing cooperative working relationships with industry.

Statistics on the use of ORNL's designated user facilities in FY 1995 are listed in Appendix A (Table A.2). One of ORNL's most heavily used facilities, the Holifield Radioactive Ion Beam Facility, is expected to resume operations as a user facility in FY 1997.

In FY 1995, more than 1000 scientists from 283 institutions conducted user experiments at ORNL. The number of industrial users grew from 131 to 164, representing 77 companies.

Of the 62 new user agreements executed during FY 1995, 8 were proprietary. In addition, 121 new projects were initiated under existing agreements. The requirement for advance payments for reimbursable costs on user projects continues to be an administrative barrier and a customer relations problem.

6.2.3 • Technology Transfer

Through the Partnership Office and the ORNL Office of Technology Transfer, the Laboratory works with other DOE facilities in Oak Ridge to enable private industry and academia to make practical application of the advanced R&D and technical expertise from these facilities. The director of the ORNL Office of Technology Transfer serves in the same

capacity for Lockheed Martin Energy Systems, Inc., (LMES) which manages the Oak Ridge Y-12 Plant and the Oak Ridge K-25 Site. The Oak Ridge Centers for Manufacturing Technology, described in Sect. 6.1.2, is an example of how the combination of Oak Ridge resources supports technology transfer.

Another example is the Technology Transfer Initiative with Minority and Small Businesses and Manufacturers. ORNL manages the program, but staff members are designated to serve all sites. The minority technology transfer program is focused on technology transfer activities and on seeking the assistance of minority and small businesses and manufacturers in recruiting minority candidates for job opportunities at DOE's Oak Ridge facilities. The program links the faculty and students of MEIs with technology opportunities and will potentially develop industrial fellowships for minority business personnel and/or MEI faculty and students.

The ER-LTR Program (see Sect. 5.1.1.5) is a key component of ORNL's technology transfer program through its support for CRADAs, personnel exchanges, and technical assistance projects.

6.2.3.1 • Resources and Staffing

The resources and staffing needed to implement ORNL's technology transfer plans are listed in Table 6.2.

6.2.3.2 • Patents and Licensing

Prior to the implementation of the new management contract for ORNL (see Sect. 7), technology transfer statistics were maintained for all of LMES (which included ORNL). In FY 1995, 52 patents were issued and 36 licenses were executed.

The Office of Technology Transfer continues to grow and improve the licensing/intellectual property of new technologies. From October 1, 1995, through May 31, 1996, 38 patents have been issued to ORNL and 21 licenses have been issued.

Program self-assessment and benchmarking against top universities and federal laboratories are leading to changes designed to strengthen the licensing program, such as

Table 6.2
Technology transfer effort
Estimated expenditures and staffing by fiscal year
for the ORNL Office of Technology Transfer

	1995[a]	1996	1997	1998	1999	2000	2001	2002
	Funding ($ in thousands—BO)							
ORTA[b] activity	1,386.7	919.0	1,026.0	1,137.0	1,256.0	1,295.0	1,335.0	1,376.0
Patent/licensing activity	924.0	1,068.0	1,100.0	1,133.0	1,167.0	1,202.0	1,238.0	1,275.0
Total	2,310.7	1,987.0	2,126.0	2,270.0	2,423.0	2,497.0	2,573.0	2,651.0
	Staffing [full-time equivalent (FTE) employees]							
ORTA activity	16.4	10.0	11.0	12.0	13.0	13.0	13.0	13.0
Patent/licensing activity	5.7	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Total	22.1	15.2	16.2	17.2	18.2	18.2	18.2	18.2

[a]Actual.
[b]Office of Research and Technology Applications.

(1) developing improved licensing strategy methods, (2) increasing the experience base of internal staff through workshops, intermediaries, and collaborative efforts, (3) encouraging entrepreneurial development, and (4) nurturing the licensee after completion of a deal.

Licenses executed in FY 1995 are listed in Table 6.3. Licensing projections are presented in Table 6.4.

6.2.4 • Science Education

Science education is recognized as one of ORNL's institutional competencies (see Sect. 2), closely linked to the R&D competencies and to the technical foundations that cross-cut them. A broad array of educational outreach and student/faculty research participation programs is designed to

- strengthen science and mathematics teaching at all levels, while encouraging student interest and learning performance;
- build and diversify the educational pipeline in disciplines that directly support DOE strategic goals and missions; and
- help to ensure the future supply of people with outstanding scientific and technical skills.

Science education activities at ORNL are coordinated through the Office of University and Science Education (OUSE), which receives funding from DOE's University and Science Education Program (see Sect. 5.1.1.1). ORNL's educational focus complements that of degree-granting institutions. The primary goal is to provide mentored, inquiry-based "hands-on" learning and research experiences for students and faculty at all educational levels. Education activities at ORNL also support local, state, regional, and national systemic reform initiatives; public science literacy; and educational technology.

OUSE's mission is to use ORNL, Lockheed Martin, local, state, regional, and national resources to be a world-class Regional Science Education Center, especially for the southeastern United States, with strong supporting constituencies at education and research institutions.

The overarching goals of OUSE are to build educational training and research partnerships that serve to

- enhance the capability, quality, and diversity of the nation's scientific and technical work force;
- strengthen ORNL technical capabilities, supporting constituencies, scientific and technical staff, and contributions;
- continue the development of education as a primary mission of the Laboratory, consistent with P.L. 101-510 (Department of Energy Science Education Enhancement Act of 1990) and Executive Order 12821 (Improving Mathematics and Science Education in Support of the National Goals), November 16, 1992;
- support National Education Goal 4: "By the year 2000, U.S. students will be the first in the world in science and mathematics achievement"; and
- contribute collective resources to the success of national science and technology initiatives, including those in mathematics and science education, high-performance computing and communications, biotechnology research, advanced manufacturing R&D, global change research, and emerging opportunities such as computational biology.

Table 6.3
Licenses executed in FY 1995

Licensee	Technology
3M	Fiber-reinforced ceramic composites by CVI (patent)
Advanced Composite Materials	SiC whisker-reinforced ceramic composites (patent)
Advanced Systems Technologies	Active and Passive Neutron Examination and Assay (APNEA) system (patent)
AlliedSignal	Fabrication of fiber preforms and structural composite materials (patent)
Alumax Technology Corp.	Fiber-optic probe (patent)
Applied Poleramic	Radiation curing of epoxy resins (patent)
Caliper MicroAnalytic Systems	Microfluidic manipulations for chemical analysis (patent)
Caliper Technologies Corp.	Microfluidic manipulation for chemical analysis (U.S. patent and foreign patent)
Ceramic Magnetics	Gelcasting (patent)
Commercial Crystal Laboratories	Superconducting thin films (patent)
Consultec Scientific, Inc.	Microbar and microcantilever sensors (patent)
DCM Consulting, Inc.	DATAVAL software (copyright)
Decision Systems International Corporation	Hazardous materials transportation expert system (HAMTES) (copyright)
Gatan, Inc.	HoloWorks software (copyright)
Genase	Genetically enhanced cellulase-producing bacterium (U.S. patent and foreign patent)
Information Systems Planning and Analysis, Inc.	Decision systems technology (patent)
Kaiser Aluminum	Fiber-optic probe (patent)
Lambda Technologies, Inc.	Method for curing polymers (patent)
Lotec, Inc.	Ceramic powders (patent)
Martin Marietta Specialty Components	Active and Passive Neutron Examination and Assay (APNEA) system (patent and copyright)
Merritt Systems, Inc.	Integrated circuit (MaskWorks)
Powell River Laboratories	ESP environmentally safe projectiles (trademark)
Powell River Laboratories	Non-lead environmentally safe projectiles (foreign patent)
Refractory Composites, Inc.	Fiber-reinforced ceramic composites by CVI (patent)
Reynolds Metals	Fiber-optic probe (patent)
Small Jobs Carpentry, Inc.	Portable microwave instrument for nondestructive evaluation of structural ceramics (patent)
SpectRx	Synchronous luminescence system (patent)
Technology Implementors, Inc.	Environmental screening system (patent)
Tel-A-Train, Inc.	"Low-Power Lasers: Beware of the Hazards" (copyright)
Teledyne Electronic Technologies	Thin-film batteries (patent)
TGM Detectors	Alpha radiation detector (patent)
Tomco Equipment	Cryoblasting (patent)
Trane Company	Triple effect absorption chiller (patent)
United Defense	Nickel aluminide alloys (patent)
	Option agreements
Technology Implementors, Inc.	Environmental screening system
Paradigm IV Technologies	Laser ablation system (option-patent)

Table 6.4
Licensing projections by fiscal year

	1995[a]	1996	1997	1998	1999
Number of new licenses	36	48	54	70	88
License income (in thousands of dollars)	590	1100	2300	4600	6000
Use of income (in thousands of dollars)					
Invention and ORTA[b] administration	234	440	920	1840	2400
Scientific or applied R&D	148	275	575	1150	1500
Award and inventor payments	148	275	575	1150	1500
Education and training	0	0	0	0	0
Other/taxes	60	110	230	460	600

[a]Actual.
[b]Office of Research and Technology Applications.

Equity and diversity are a high priority in ORNL educational programs. Established collaborations with multicultural educational institutions not only support the continuing development and growth of these institutions as academic centers of excellence but also enable DOE and its contractors to diversify their present and future work force.

Through the ORNL Regional Science Education Center, opportunities have been provided for more than 25,000 students and teachers each year. (Given the changing funding base in this area, future participation may decline.) Table A.3 in the Appendix lists these activities and the number of participants. They include

- partnerships with more than 60 elementary and secondary schools and/or school systems, colleges, and universities emphasizing outreach to underrepresented and underserved populations (women, minorities, the economically disadvantaged, and people with disabilities);
- student and faculty research participation through DOE's long-standing University Laboratory Cooperative Program and through two newer initiatives, the undergraduate Science and Engineering Research Semester and the secondary-level Teacher Research Associates (TRAC) program;
- the Oak Ridge Educational Network, which connects schools and individuals to the Internet;
- the Ecological and Physical Sciences Study Center, which began in 1984 as ORNL's core program for K-12 students and teachers and has served up to 24,000 participants annually through 40 different half-day instructional units;
- Project SMART (Science/Math Action for Revitalized Teaching), a prototype rural-urban partnership that links three East Tennessee school systems, ORNL, and the Oak Ridge Institute for Science and Education (ORISE);
- the Adventures in Supercomputing teacher institutes and student programs, now reaching schools in five states under the High Performance Computing and Communications Program;
- the five-state Academy for Teachers of Science and Mathematics, a University of Tennessee (UT)–ORNL partnership with federal, state, and corporate (Lockheed Martin) support, and many other teacher enhancement activities;

- aggressive outreach to multicultural educational institutions through customized internships and other research participation opportunities;
- two ORNL-based UT graduate schools—the UT-ORNL Graduate School of Biomedical Sciences and the UT Graduate Program in Ecology—and joint institutes and research centers in many other areas;
- participation in the DOE Science and Technology Alliance, which links ORNL, Los Alamos National Laboratory, and Sandia National Laboratories with four minority educational institutions;
- an annual conference on women in science and technology, jointly sponsored with ORISE; and
- postgraduate training initiatives, including the new ORNL Postdoctoral Research Associates Program, which now bring well over 200 young investigators to the Laboratory for extended assignments with ORNL mentors.

6.3 • Developing Strengths for Mission Needs

6.3.1 • Laboratory Directed R&D

The principal objective of the ORNL Laboratory Directed R&D (LDRD) Program, as discussed in Sect. 5.3, is to provide financial support for innovative R&D ideas that, while within the general mission of the Laboratory, have no direct programmatic funding. The LDRD Program comprises two major activities: the Seed Money Fund, which supports smaller projects (generally ≤$100,000) of shorter duration (<1 year), and the Director's R&D Fund.

Proposals for the Director's R&D Fund are solicited from the scientific and technical staff in June and are reviewed through line management; most are selected by the Laboratory's senior managers, with 5 to 10% of the available funds allocated individually by Laboratory associate directors to proposals from within their directorates.

For FY 1997, proposals were encouraged in two categories: "Enhancing R&D Competencies" and "Gene and Protein Function." The Laboratory's senior managers selected these two categories to foster ORNL's recognition and innovative R&D capabilities in these key fields.

6.3.1.1 • Enhancing R&D Competencies

The objective of the "Enhancing R&D Competencies" category is to strengthen and invigorate ORNL's broad scientific and technical foundations and to develop new capabilities in support of the Laboratory's mission (see Sect. 1). Target areas in this category are

- measurement science,
- advanced materials and processing,
- neutron science and technology,
- high-performance computing, and
- environmental science and technology.

6.3.1.2 • Gene and Protein Function

The "Gene and Protein Function" category has been selected to establish ORNL as a leading research center in this area, as part of the Laboratory's major initiative in functional genomics described in Sect. 4.2. Because of the striking similarity of the mouse and human genomes, the function of human genes and proteins can be explored using the mouse as an experimentally malleable surrogate of the human. ORNL's historical expertise in mouse genetics, mouse mutagenesis, protein chemistry, and enzymology; its unparalleled repository of mouse mutants carrying defective genes; and its extensive resources in technology and computing place the Laboratory in a unique position to lead a national effort in gene and protein function.

The specific goals of this category support two objectives: (1) to develop new processes, equipment, and instrumentation to achieve highly efficient operation of a modern mammalian (mouse) research facility, and (2) to develop new processes, techniques, equipment, and instrumentation to achieve a significant decrease in the time required to determine the function of genes and proteins. These specific goals are

- high-efficiency DNA and protein isolation;
- instrumentation, robotics, and analytical technologies for automated, high-throughput analysis of DNA fragments and proteins;
- design of cognitive systems that incorporate advanced technology to optimize the manipulation of DNA and protein samples and other biological specimens;
- improved methods (e.g., cryopreservation) for the maintenance and distribution of mouse strains and other biological specimens such as DNA and protein samples;
- development of computer databases on mouse genetic lines and of tools for the detailed molecular, physiological, and pathological analysis of mouse mutations and mouse mutant strains maintained at ORNL;
- enhanced techniques (e.g., X-ray and neutron diffraction) to determine the molecular structures and properties of nucleic acids and proteins; and
- techniques for high-throughput cloning and expression of cDNA and for antibody production from recombinant proteins.

6.3.2 • Program Development Activities

Program development activities at ORNL are focused on maintaining the R&D expertise available to DOE and enhancing the Laboratory's capabilities to carry out DOE missions. During the planning period, increasing emphasis will be placed on opportunities in emerging areas, such as gene function and biotechnology, and areas in which pressing national needs exist, such as transportation and environmental protection. Activities are directed toward identifying and pursuing new opportunities to apply ORNL's strengths to mission-related needs. They also serve to broaden the Laboratory's customer base and provide a basis for partnerships with universities, industry, other DOE laboratories, other federal agencies, and state and regional organizations.

6.4 • Information and Communication

ORNL plans to use its expertise and extensive investments in computing and networking technology to develop a networked information management strategy based on distributed information access. The World Wide Web (WWW) will become the information highway of choice for global communication about ORNL's research technology products and services.

As a networked laboratory, ORNL plans to use the Internet and the WWW to blend its internal and external information sources into a road map that everyone can understand and will use as a valuable resource. Information dissemination on the WWW will become a natural step in the information life cycle. Information products from ORNL's information centers and databases will be distributed via WWW servers. Subscriptions to key information will be obtained to maximize the availability of information to ORNL's staff. These plans are discussed in the ORNL *Strategic Plan for Computing,* which is summarized in Appendix B.

6.4.1 • Scientific and Technical Information

Scientific and technical information is a primary product of ORNL's R&D efforts. As a unique national resource, it must be managed wisely throughout the varied stages of its "life cycle" (e.g., generation, transfer, access, packaging, storage, and retrieval). Proper management enhances the value of this information as a tool for accomplishing DOE missions and increases its availability to various audiences, including U.S. industry and the general public.

ORNL has extensive scientific and technical information resources. For example, the Laboratory is home to one of the most extensive and authoritative complexes of scientific data and information analysis centers in the United States. A complex of about two dozen information analysis centers is managed by ORNL's Environmental Sciences and Health Sciences Research divisions. More than 200 textual and/or numeric databases cover various technical disciplines in support of DOE and other customers.

ORNL expects to continue collaborations with NASA, the National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, the Department of Health and Human Services, and other organizations (see Sect. 5.2) in meeting national needs for scientific and technical information. These collaborations will be structured to take advantage of new technologies for information management such as the WWW.

6.4.1.1 • Life Cycle Management of Scientific and Technical Information

Working within the Strategic Plan of DOE's Office of Scientific and Technical Information (OSTI), ORNL is devising a method of document clearance that will reduce the number of approvals required for a document, capture the needed approvals electronically, and also attach an electronic version of the full text of the document. This transition will allow for better access to scientific and technical information at greater speed and lower cost.

ORNL is also working to allow Laboratory staff members to enter information directly into the ORNL publications database. This effort supports the use of WWW technology to avoid an entire level of data input, and it will also provide publications information for use as a productivity measure in real time. Currently, this information is a "lagging indicator" with a two-year lag time.

A separate effort is under way to increase the number of software packages submitted to OSTI's Energy Science and Technology Software Center.

6.4.1.2 • Scientific and Technical Information Centers and Databases

Brief descriptions of selected ORNL information centers and databases are presented here. Information about many of these activities is available from ORNL's WWW site, at http://www.ornl.gov.

ARM Archive

The Atmospheric Radiation Measurement (ARM) archive stores, manages, and processes data collected for the ARM Program, part of DOE's contribution to the U.S. Global Change Research Program, and makes these data available to ARM scientists and the wider science community via the Internet and the WWW. The ARM archive activity is closely integrated with the Center for Computational Sciences (CCS) and the Center for Global Environmental Studies at ORNL (see Sect. 6.1.1). The Intel Paragon supercomputers of the CCS and the massive ARM archive will be linked to allow complete interaction of both systems. In its mature state, the archive will be a worldwide resource of atmospheric radiation information for refining general circulation models and for understanding atmospheric phenomena such as cloud formation and cloud optics.

The archive includes a data reception and cataloging system, a database for metadata about the stored files, a user interface for data retrieval, and a mass storage system. Since its inception in June 1992, the archive has stored over a million files, totaling 40 gigabytes. This is expected to increase to millions of files, or several terabytes, during the remaining years of the program. ORNL staff in environmental science, computer science, and computing continue to explore methods of meeting the increasing demands for information storage.

Carbon Dioxide Information Analysis Center

The Carbon Dioxide Information Analysis Center (CDIAC) is a fully integrated information analysis center that acquires or compiles, documents, archives, and distributes data and other information related to CO_2, other greenhouse gases, and climate in support of the U.S. Global Change Research Program. CDIAC is formally recognized by DOE as a specialized information analysis center in its area of expertise.

Extensive quality assurance audits are performed on databases critical to understanding global change. CDIAC supports the extensive data and information needs of the international research, policy-making, education, and corporate communities to assist them in the evaluation of complex environmental issues associated with elevated concentrations of CO_2 and other greenhouse gases in the atmosphere. CDIAC staff identify users' needs by attending workshops, reviewing literature, and maintaining personal contact. The center obtains and evaluates data, articles, and reports for potential worldwide distribution; produces digital numeric data and computer model packages; distributes DOE reports; and publishes the newsletter *CDIAC Communications* (available on the WWW) and the *DOE Research Summary* series.

CDIAC also houses the World Data Center–A for Atmospheric Trace Gases (WDC-A). The center is a component of the International Council for Scientific Union's World Data System, a system of 44 data centers worldwide that facilitates research data

exchange and archiving for the international research community. WDC-A provides the international scientific community with a system to manage critical data related to trace gas cycling and will acquire, assure the quality of, document, archive, and distribute data and information focused on the study of atmospheric trace gases, particularly those that are important to the analysis of issues for global change.

Chemical Unit Record Estimates Data Base

To develop guidelines and limits for controlling chemical substances by a valid scientific approach, various offices within the Environmental Protection Agency (EPA) gather and evaluate information and prepare assessment reports. The Chemical Unit Record Estimates (CURE) Data Base, a comprehensive database designed and implemented by the EPA's Office of Health and Environmental Assessment and ORNL, communicates this information within the agency and facilitates the chemical regulatory process.

CURE currently comprises five subfiles: a chemical dictionary, a bibliography file, an experimental data file, a central summary file, and a comment file. The chemical file lists 1900 chemicals classified according to the structural categories developed in the EPA Genetic Toxicology Program. This unique database provides a basis for structural activity to span genetic toxicology, low-dose toxicology, and carcinogenicity.

Distributed Active Archive Center

ORNL is the site of the National Aeronautical and Space Administration (NASA) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics for the Earth Observing System Data and Information System (EOSDIS). EOSDIS currently consists of nine DAACs. It is a key component of NASA's contribution to efforts to develop a predictive understanding of the global environment through the U.S. Global Change Research Program. The ORNL DAAC provides data and information about the earth's biogeochemical dynamics and ecology to the global change research community, policy makers, educators, and interested members of the general public. Information about the ORNL DAAC and its data holdings is available on the WWW (http://www-eosdis.ornl.gov).

Environmental Mutagen Information Center

The ORNL Environmental Mutagen Information Center (EMIC) collects and analyzes experimental data on the evaluation of chemical agents for genotoxicity. Since 1968, EMIC has indexed more than 85,000 papers reporting on more than 22,000 chemicals.

These data are used in the EPA's GENE-TOX database, which provides information allowing correlation of chemical structure and genetic activity, and in the EMIC database sponsored by the EPA and the National Library of Medicine. Information from these databases is incorporated into considerations for regulatory action and is included in the publications of the International Agency for Research on Cancer.

Human Genome Management Information System

The Human Genome Management Information System (HGMIS) provides technical communication and information services for the DOE Office of Health and Environmental Research (OHER) Human Genome Program Task Group. HGMIS facilitates research by

(1) helping to communicate genome-related matters and investigations to contractors, grantees, and others via hard copy and electronic media; (2) serving as a clearinghouse for information on the U.S. genome project; and (3) reducing duplication of research efforts by providing a forum for information exchange among Human Genome Project investigators worldwide. HGMIS also occasionally compiles and organizes administrative data for DOE by preparing reports and meeting minutes, conducting information searches, writing and editing, and assisting DOE staff at meetings.

HGMIS publishes the bimonthly newsletter *Human Genome News* for OHER and produces a primer on molecular genetics and reports on the DOE Human Genome Program, contractor-grantee workshops, and related subjects. Many of these publications are available electronically. More than 33,000 copies of the *Primer on Molecular Genetics,* which was expanded and revised by HGMIS from an earlier DOE document, have been distributed, and the WWW version is accessed about 16,000 times each month. To support DOE's commitment to public education, HGMIS also provides space on its WWW site for drafts of the high school genetics curriculum being developed by the DOE-funded Biological Sciences Curriculum Study Group. The Genetic Privacy Act, written at Harvard Law School, is also accessible at the HGMIS site. HGMIS maintains and updates the Genetics section of the Virtual Library from CERN (Switzerland) and the DOE genome project–specific pages. HGMIS also collaborates with the Einstein Institute for Science, Health, and the Courts to help educate the judiciary on genetics and other biomedical issues via the HGMIS WWW site. Between January and July 1995, usage of HGMIS WWW text files increased more than 20-fold, from 444 to 9326 information requests a month.

Radiation Shielding Information Center

The Radiation Shielding Information Center (RSIC) is a specialized information analysis center (SIAC) authorized to collect, analyze, maintain, and distribute computer software and data sets in the areas of radiation transport and safety. RSIC follows the policy and procedure directives defined in DOE Order 1430.1D, "Scientific and Technical Information Management," June 30, 1994, and is formally recognized by DOE as an SIAC in its area of expertise.

Established in 1962, RSIC's mission is to provide in-depth coverage of the radiation transport field to meet the needs of the international shielding community. RSIC collects, organizes, evaluates, and disseminates technical information involving shielding and protection from the radiation associated with fission and fusion reactors, outer space, accelerators, weapons, medical facilities, and nuclear waste management. Specific topics include

- the physics of the interaction of radiation with matter,
- radiation production and sources,
- nuclear criticality safety,
- radiation protection and shielding,
- radiation detectors and measurements,
- shielding materials properties,
- radiation waste management,
- shields and shipping cask design,
- radiation safety and assessment, and
- atmospheric dispersion and environmental dose.

RSIC receives funding from the Nuclear Regulatory Commission, the Defense Nuclear Agency, and several DOE programs.

RSIC staff members collect, maintain, analyze, and distribute technical computing software in the areas of shielding and transport; they also provide technical consultations with requesters to resolve discrepancies, assist in installation, and answer technical inquiries on radiation transport matters. RSIC also

- publishes and distributes a monthly newsletter to announce corrections, updates, or new packages, as well as to notify the shielding community of items of interest;
- conducts seminars and workshops on computing methods and code systems of particular interest to the user community;
- participates in a formal cooperative arrangement between DOE and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development in the field of nuclear data and computer programs through international software exchange;
- works closely with the DOE Energy Science and Technology Software Center to avoid overlap and duplication of effort in software development and distribution;
- maintains computerized databases of shielding information selected by technical analysts; and
- exchanges visits and guest assignments with shielding installations throughout the world to collect and share shielding technology for mutual benefit.

Toxicology Information Response Center

The Toxicology Information Response Center (TIRC) offers direct access to a wide variety of scientific and technical databases on a cost-recovery basis. Originally organized under the sponsorship of the National Library of Medicine to serve as an international center for toxicology and related information, TIRC is staffed by the Biomedical and Environmental Information Analysis Section of ORNL's Health Sciences Research Division and draws on the extensive in-house regulatory and compliance technical resources developed by this section. These resources include customer-specific compliance reports, environmental regulation reference books, monthly regulatory update tables, and other user-specific products.

6.4.2 • Public Information and Outreach Activities

Communication of information about the Laboratory's programs, activities, and staff to the public is a high priority. Programs are in place to address the needs of both the general public and the "internal public"—ORNL employees.

Information products include the *ORNL Review,* the Laboratory's R&D magazine; a set of brochures describing ORNL's R&D programs; press releases describing activities at ORNL; and a column by the Laboratory Director for use by area newspapers. All of these information products are available on the WWW, in support of ORNL's plans to use this tool for communication about its research, technology, products, and services. Communications designed specifically for the internal public include a regularly updated WWW feature, "ORNL Today"; *Lab Notes,* a monthly newsletter available both electronically and in hard copy; and periodic Laboratory-wide meetings, which have been used to transmit information about ORNL's reengineering effort.

ORNL hosts family and community days and encourages members of the community to visit. A combined Family Day and Community Day was held in October 1995, and a Take

Your Child to Work Day was held in July 1996. Regularly scheduled breakfasts are held with elected officials from neighboring communities to exchange information and showcase ORNL's research activities. Visitors to ORNL may participate in prearranged general orientation tours, customized group tours, self-guided driving tours, or public bus tours originating at the American Museum of Science and Energy in the city of Oak Ridge.

The public bus tour was introduced as a pilot program in 1995 and attracted 618 visitors from 41 states and 29 noncitizens from 12 countries. The 1996 tours, offered from March 1 through October 31, include a commentary on the city of Oak Ridge, the east end of the Oak Ridge Y-12 Plant, ORNL, and the Oak Ridge K-25 Site. The ORNL portion of the tour features a stop at the Graphite Reactor, a National Historic Landmark.

Tours serve to educate local, regional, and national groups about DOE-sponsored research and technology in the Oak Ridge area. They are also expected to help increase science literacy and to serve as a means of obtaining feedback on how Oak Ridge is perceived by the public.

Laboratory staff participate in educational fairs, environmental fairs, and other community events. Information about the environment of the Oak Ridge Reservation is disseminated to the public, and the public is involved in decisions concerning management of the reservation. Public education activities at the Oak Ridge National Environmental Research Park include special events, such as wildflower hikes and bird walks, and "hands-on" experiences for precollege students.

6.4.3 • Administrative Information

ORNL will continue to improve employee access to information needed in the daily conduct of operations. Internet technologies are being applied to increase desktop access to information with an emphasis on reducing costs and increasing efficiency. The Administrative Computing Steering Committee is the focus for many of these tasks, which include

- moving to standards-based desktop electronic mail systems;
- using the WWW for ORNL command media (directives and guidance);
- using the WWW as the preferred interface for business applications, such as
  - a Property Information Access and Update system,
  - employee information,
  - financial and project management information systems to provide precise meaningful readily available information on the status of an organization or project,
  - the Corporate Information Center,
  - the Central Publications Registry, and
  - the Software Product Update and Distribution System;
- evaluating and implementing new applications through the Operational Software Review Board; and
- upgrading operating systems and telecommunications.

The committee also sponsors working groups to address specific initiatives, such as the development of electronic forms and a secure electronic signature process and the reengineering of a process for collecting information on guests, subcontractors, leased personnel, and consultants.

6.4.4 • Information Resource Management

ORNL is committed to managing and using its technical and administrative information as institutional and multinational assets. Timely and reliable information is critical to meeting objectives. The need for effective management of the large volume of information throughout ORNL has become vital. Steps are being taken to strengthen management attention to information as an asset and to improve user involvement in the effective use of information resources. The *Strategic Plan for Computing at Oak Ridge National Laboratory* (ORNL/PPA/INT-94/2, September 1994), which is summarized in Appendix B, contains goals directed toward improved information resource management (IRM).

To facilitate access and utilization, information will be made available at the point of use, usually the desktop, through a common interactive interface. Because of the variety of desktop configurations in place at ORNL this requires an interface that works for the Microsoft Windows, Mac™ OS, and UNIX® environments. Because of its cross-platform client capabilities and its increasing technical functionality, the WWW is currently ORNL's tool of choice for delivering information and administrative processes to all ORNL staff and a major means of communication with the outside world. As WWW functionality increases and more information is communicated via the WWW, ORNL staff will operate from a more complete and current information base, and administrative tasks will be accomplished more efficiently and with improved quality. Further development of ORNL WWW capabilities requires an investment in this challenging and highly distributed utility.

The Laboratory's objectives for a coordinated IRM program include

- increased desktop access to information via Internet technologies;
- acquisition or development of tools, techniques, and applications that support the information needs of ORNL;
- maximum participation in deployment of corporate applications to enable appropriate implementation for ORNL;
- efficient records management via efforts now under way to inventory and capture key attributes of archival records into electronic retrieval systems; and
- enhanced electronic distribution of documents (i.e., cradle-to-grave electronic publishing and dissemination).

7 • Laboratory Operations

On January 1, 1996, the management of ORNL was transferred from Lockheed Martin Energy Systems, Inc., (LMES) to a new Lockheed Martin corporate entity, Lockheed Martin Energy Research Corporation (LMER). This new arrangement provides ORNL with the opportunity to maximize the advantage of its designation as a Federally Funded Research and Development Center. It also allows ORNL to work with the U.S. Department of Energy (DOE) to establish policies and procedures tailored for the Laboratory's research and development (R&D) mission. It gives ORNL both increased control over operations and costs and increased responsibility for its future.

Another change in the Laboratory's operating environment was formalized on January 11, 1996, when ORNL and DOE's Oak Ridge Operations Office (DOE-ORO) agreed to the following set of partnering principles:

- DOE oversight will move from "prescription and permission" management to performance evaluation.
- DOE will not duplicate oversight responsibility which resides in other agencies.
- The intent of oversight will be to assess contractor management systems, commensurate with the risk to DOE.
- The DOE/Laboratory complex will institute outcome-based management assessment and apply best management practices and commonly accepted industry standards.
- Laboratory contractors have full responsibility and accountability for all of their administrative, programmatic, and regulatory functions.
- DOE's role is scientific program definition, stewardship, planning and funding of Laboratory programs and infrastructure, and performance review.
- Consolidate management activities by eliminating redundancy and integrating functions to achieve cost effectiveness.

The new environment for the Laboratory is reflected in this section of the institutional plan. A reengineering effort, discussed in Sect. 7.1, was launched in March 1996 to reduce costs and enhance R&D, consistent with DOE's Strategic Alignment Initiative, the new contract, and the partnering principles. Plans and activities in management practices—including a new business management function—are described in Sect. 7.2. Environment, safety, and health (ES&H) activities have been realigned within the Operations, Environment, Safety, and Health (OES&H) Directorate; they are reviewed in Sect. 7.3. Waste management services and plans are discussed in Sect. 7.4. Infrastructure and support activities are discussed in Sect. 7.5. The Laboratory's nuclear operations are described in Sect. 7.6.

7.1 • Reengineering ORNL

ORNL is engaged in a reengineering effort that is focused on reducing costs and enhancing R&D. This effort is aimed at providing

- a corporate structure for ORNL that supports and is responsive to the R&D mission,
- a working environment that ensures maximum scientific productivity and staff member reward,
- operating policies and controls that ensure the highest quality R&D performance in compliance with all applicable requirements, and
- "Best Industry Practices" support and services to R&D programs at minimum cost.

This Laboratory-wide reengineering effort is part of ORNL's continuing commitment to implementation of the Secretary's Strategic Alignment Initiative. It builds on the analyses conducted as part of ORNL's transition to the DOE-LMER management contract and on the recommendations made by Ernst and Young LLP, a consulting firm retained by ORNL to help guide the reengineering effort.

A Reengineering Steering Committee is charged with integrating the transition analyses and the Ernst & Young LLP recommendations, developing a road map for the next two years, and identifying working groups to implement the road map. Process reengineering teams are addressing high-priority targets for reengineering: finance and business management, human resources, and research support services. Process improvement teams are being chartered to address and implement cost-effectiveness goals within all organizational units.

These teams are charged with improving ORNL productivity and cost-effectiveness, enhancing mission performance, involving ORNL staff and subject matter experts, and focusing on the Laboratory's customers. The following goals have been established:

- significant improvements (>20%) in business management systems and costs,
- human resources processes that support the workplace of the future at lower cost (>20%),
- research support services that deliver 20–40% more output per dollar,
- significant improvements in procurement cycle time and costs,
- a significant reduction in Laboratory overhead,
- a significant reduction in division overhead,
- implementation of "Work Smart" standards with resulting cost reductions, and
- a 15% increase in direct scientific and technical effort per dollar over two years.

Implementation of recommendations has begun, including the integration of the overhead budget review with reengineering and the establishment of reengineering goals for the Laboratory's R&D divisions. Implementation will accelerate during FY 1997 with the completion of studies being conducted by the process reengineering teams. Reengineering should be complete in FY 1998. Continuous improvement is integral to the process and will extend beyond the completion of the reengineering effort.

7.2 • Management Practices

7.2.1 • Business Management

To support the new operating environment, ORNL has established a business management function within the OES&H Directorate. This function includes finance and

budget, contract administration, capital asset management (see Sect. 7.5.1), business interfaces with LMES, and activities supporting a smooth transition from LMES to LMER.

ORNL began a serious examination of its costs in FY 1992. With support from DOE, the Laboratory instituted an overhead reduction project that brought the overhead rate down to 45% from a projected 54%. In FY 1995, the overhead rate was 44%.

ORNL's cost savings and avoidance program continues, supported by discussions with the DOE ORNL Site Office, to obtain DOE objectives for the effort and to identify opportunities for efficiencies. The program includes project promotion and identification, project reporting and validation, and progress reports to the DOE ORNL Site Office and DOE-ORO. During FY 1996, ORNL identified over $20 million in cost savings and avoidances.

Additional structural changes in the way ORNL does business with DOE are being pursued, building on the new partnering principles and on the establishment of "Work Smart" standards based on the "necessary and sufficient" process now under way (see Sect. 7.3). These changes should provide further opportunities for overhead reduction.

The business management process reengineering team (see Sect. 7.1), which includes representatives from DOE-ORO and from LMES, is charged with determining the most cost-effective and user-friendly financial, acquisition, and human resources systems, processes and high-level business rules at ORNL and LMES. This team is addressing areas such as cost accounting systems, project planning and management, asset management, and procurement.

7.2.2 • Performance Measurement

7.2.2.1 • Individual Performance

ORNL uses a performance planning and review system to evaluate individual job performance. Each salaried employee develops an annual performance plan with specific goals under the guidance of his or her supervisor. Supervisors annually appraise employee performance, using progress toward achieving these goals as input for the appraisal.

The scope of work for the human resources reengineering team (see Sect. 7.1), which includes a representative from DOE-ORO, includes performance appraisal. The team is developing recommendations for a meaningful and equitable performance appraisal system that successfully evaluates and motivates employees. Implementation of these recommendations is expected in FY 1997.

7.2.2.2 • Division and Program Performance

Divisions and programs use strategic planning to set performance goals; performance is monitored internally and by advisory committees. An annual statistical publication, *ORNL Facts and Trends,* provides Laboratory management with data on R&D productivity in each division.

7.2.2.3 • Laboratory Performance

The contract between DOE and LMER provides for the use of performance measurements to promote continuous improvement and provides a basis for evaluating contractor performance. Performance measures have been developed in four fields: programmatic, institutional management, operations support, and administrative, as listed in Table 7.1.

Table 7.1
DOE-LMER contract performance measures

Field	Number	Performance Area	Units
Programmatic performance	RD-A	Research quality	Score
	RD-B	Relevance to DOE missions or national needs	Score
	RD-C	Effective and efficient research management	Score
	RD-D	Successful construction and operation of research facilities	Score
	RD-E	Performance on licenses and patents	Index
	RD-F	Commercial use of licensed technology	Dollars
Institutional management performance	IM-A	Amount of private, state, and federal (non-DOE) funded work per R&D dollar	Percent
	IM-B	Research labor productivity	Index
	IM-C	Improvement in management diversity	Percent
	IM-D	Advancement of work force diversity[a]	Index
Operations support performance	OS-A	DOE Safety Index	Index number
	OS-B	Nuclear Safety Violation Index	Number
	OS-C	Environmental permit violations	Number
	OS-D	Control of property loss[a]	Percent
	OS-E	Cumulative risk management (with time and dollar *de minimis* values)[a]	Index
Administrative performance	AM-A	Percent of subcontracts placed with small businesses	Percent
	AM-B	Percent of subcontract placed with small, disadvantaged businesses and small, women-owner businesses	Percent
	AM-C	Value of contracts to HBCUs and minority educational institutions related to total educational contracts	Percent
	AM-D	Cost reductions[a]	Score

[a]This performance measure will be developed and evaluated later in the contract period and will be considered for addition to the contract at that time.

Initial performance targets have been determined, and LMER will annually report the performance measures to DOE. Standards of performance will be reviewed annually, and processes are in place for negotiating and establishing changes in performance measures as needed.

7.2.3 • Quality Assurance Program

A formal Quality Assurance (QA) Program applies to all activities conducted by or for ORNL. This program incorporates planning for prevention of problems, quality control to assure conformance to requirements, and continuous performance improvement. Independent audit functions verify compliance with QA requirements and evaluate the effectiveness of QA programs. Self-assessments are conducted to evaluate performance and identify areas of improvement. QA staff in the OES&H Directorate support ORNL managers in the implementation of programs that foster effective R&D, accomplish ES&H objectives, and meet quality requirements.

7.2.4 • Human Resources

Over the last five years, changing budgets in specific programmatic areas have led to reassignments and reduced staff levels (see Tables A.4 and A.5 in the Appendix). Rather than diminishing ORNL's commitment to the development and management of human resources, these changes have prompted the Laboratory to reaffirm its goal, identified in the *ORNL R&D Strategic Plan,* to recruit and retain the staff needed to achieve programmatic goals. Consequently, activities in staff recruiting, retention, and diversity are being refocused or intensified. ORNL's commitment to human resource development and management is evident in many areas; these include valuing diversity, recruiting and hiring the best, and promoting employee development.

The Laboratory continues to place high-level emphasis on equal employment opportunity (EEO) and affirmative action (AA), in addition to promoting acceptance of and appreciation for cultural diversity and inclusion and accommodating the needs of a changing work force. The Diversity Council, chaired by the Associate Laboratory Director for Life Sciences and Environmental Technologies, continues to develop strategies to meet EEO/AA challenges.

The fourth annual work force diversity awards and recognition event, featuring a luncheon and a workshop, was held on June 19, 1996, to recognize outstanding contributions by individuals and organizations to supporting and promoting ORNL's diversity goals. The workshop provided an opportunity to share lessons learned and senior management expectations and experiences in managing diversity. The keynote speaker for the workshop was Dr. Walter Massey, president of Morehouse College and former director of Argonne National Laboratory and the National Science Foundation.

Notable accomplishments in work force diversity include

- significant interfaces with historically black colleges and universities (HBCUs), including technical and staff support for the establishment of a graduate program in radiation protection at Florida A&M University and a partnership with North Carolina A&T University that has included over $2 million in subcontracting activity;

- participation in the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc. (GEMS), which has resulted in the employment of three ORNL staff members; and
- a partnership with the Southeastern Consortium for Minorities in Engineering (SECME), which included seven interns during the summer of 1995.

The ORNL Diversity Council completed and submitted to DOE a Diversity Plan that was conceived and developed by teams of Laboratory employees. The teams focused on diversity in the work force, educational outreach, community involvement and outreach, and economic development including technology transfer. Goals, strategies, and metrics were identified for each area. Work Force Diversity Representatives and line managers from each organization reviewed and commented on the actions. Strategies outlined in the plan (see Table 7.2) will be the template for future human resource activities.

In an effort to retain staff essential to ORNL's missions, the Employee Development Task Team was chartered to take a critical look at employee development opportunities at ORNL and to suggest enhancements. Table 7.3 shows the educational backgrounds of Laboratory staff members. The team reviewed and considered issues identified from two employee surveys and an assessment by the human resources consulting firm Watson Wyatt. Issues identified include developmental assignments, mentoring, and job rotation. In addition, the task team designed a survey for identifying best practices and is currently conducting the survey at five companies. Adapting those best practices at the Laboratory, analyzing and applying lessons learned from the internal surveys and assessments, and meeting EEO/AA and diversity challenges—all will receive special emphasis in ORNL's planning for human resources as the Laboratory moves through reengineering and adapts to future shifts in funding.

Table 7.2
Selected work force diversity strategies from the Diversity Plan

A. Nontraditional Recruiting Efforts
   1. Establish a clerical co-op program and enhance other student programs such as SECME and GEMS
   2. Coordinate marketing with the National Urban League's Black Executive Exchange Program
   3. Promote sabbaticals to HBCUs and minority educational institutions (MEIs)
   4. Develop recruiting opportunities with the user groups and the Minority Business Outreach Program

B. Staff Development and Retention
   1. Communicate and make available to staff information on development opportunities and career programs
   2. Reevaluate company policies on sabbaticals and work schedules
   3. Promote effective use of mentoring

C. Educational Outreach
   1. Identify opportunities to enhance interface with and support for HBCUs and MEIs, including advisory positions, visiting lectureships, sabbaticals, adopt-a-department programs, and graduate programs
   2. Expand pre-college programs to include the Special Technology Education Partnership for computer-aided design training, Tennessee Goals 2000 for math and science skills development, and SECME faculty in-service training opportunities
   3. Promote R&D collaboration including the HBCU Materials Science Alliance and Montana Consortium for water quality research

Table 7.3
ORNL staff composition (as of December 31, 1995)[a]

	Ph.D.	M.S.	B.S./B.A.	Other	Total
		Professional staff			
Scientists	359	134	92	24	609
Engineers	291	273	255	91	910
Management/administrative	178	257	267	287	989
		Support staff			
Technicians	0	9	81	361	451
All other	0	3	71	1351	1425
Total ORNL staff	828	676	766	2114[b]	4384

[a]Includes full-time and part-time employees.
[b]Includes 233 employees with A.S./A.A. degrees.

7.3 • Environment, Safety, and Health

7.3.1 • ES&H Goals and Objectives

ORNL is committed to excellence in all activities and to cost-effective operation in compliance with all applicable ES&H laws and regulations. This commitment is reflected in the Laboratory's mission statement (see Sect. 2) and in the *ORNL R&D Strategic Plan* (summarized in Sect. 3), which identifies the goal of conducting all operations in a safe and environmentally responsible manner.

The management contract between DOE and LMER establishes the fundamental ES&H expectations of DOE. The Laboratory has established planning goals and mechanisms to help achieve the ES&H goals defined in the DOE Strategic Plan. Work is also under way to develop target milestones and success indicators by which ES&H performance measures, objectives, and metrics can be established. Funding of ES&H for full compliance continues to be a challenge to Laboratory management, which will work within the constraints of decreasing budgets and use risk-based prioritization of activities as a basis for planning and budgeting.

7.3.1.1 • Support for DOE Strategic Plan ES&H Goals

DOE Strategic Plan ES&H Goal 1: Worker Empowerment and Protection

ORNL's occupational safety and health programs have undergone aggressive restructuring to empower workers and to achieve full compliance with established limits. All ORNL workers are empowered to stop any work that is considered to be a serious threat to the environment or to the safety of workers or other personnel. This empowerment has been reaffirmed by an ORNL Management Directive, which also specified that no one is required to participate in work that is believed to be a threat to worker health or safety or to the environment. Bargaining unit employees have full-time personnel assigned to the Office of

Safety and Health Protection for direct input to ES&H activities and to assist in performing ES&H assessments.

DOE Strategic Plan ES&H Goal 2: ES&H Performance Requirements

ORNL is fully committed to the establishment of performance requirements to measure progress toward continuous improvement. Three levels of ES&H performance measures are used at ORNL. Contractual performance measures are established in the DOE-LMER management contract. Secondary measurements developed by line management for use in assessing performance relative to the contractual measures include a pilot ES&H oversight reduction program and a Laboratory-wide performance indicators program.

ORNL and DOE have worked together to develop the pilot program, which uses a performance-based management system to reduce ES&H oversight costs while maintaining or improving ES&H performance. Performance measures to assess ORNL's ES&H program have been developed by ORNL ES&H staff and DOE personnel. They focus on improved and positive performance and include criteria that are objectively measurable and allow the observation of meaningful trends. Results are reported to DOE each month.

The ORNL Performance Indicator Program drives improvement and characterizes line management progress toward meeting performance measures. Performance indicators were developed by ORNL research and operations divisions to support the performance measures established in the pilot ES&H oversight reduction program and in the DOE-LMER contract. The indicators are used by ORNL ES&H managers, division directors, and senior managers to aid in assessing the performance of programs and functional areas.

DOE Strategic Plan ES&H Goal 3: ES&H Priorities

The annual DOE ES&H Management Plan provides a vehicle for identifying ES&H issues and setting priorities. Although not all ES&H issues at ORNL are fully funded, the Activity Data Sheets (ADSs) contained in these plans address the structure and methods of protecting the environment and worker safety and health.

Risk-based priority ranking of ORNL programs and activities is performed to ensure that the most significant activities receive primary consideration for funding from the limited resources available. Through the ES&H planning process, significant attention is drawn to underfunded or unfunded ES&H issues. ORNL has also established ES&H internal implementation plans that are monitored by the Environment, Safety, Health, and Quality (ESH&Q) Committee (see Sect. 7.3.3.2).

DOE Strategic Plan ES&H Goal 4: Respectable ES&H Performance

ORNL works to continuously improve its ES&H programs and reporting mechanisms to ensure sharing of information, lessons learned, tracking and trending, and accomplishment of corrective actions. The agreements in principle established between DOE and the state of Tennessee and the resources dedicated to these agreements by ORNL management are evidence of the efforts to earn public trust and credibility. Hundreds of formerly classified documents have been released for public viewing through the Health Studies Agreement, the Tennessee Oversight Agreement, and the Human Radiation Experiments Studies. The most recent phase of the Health Studies Agreement resulted in the declassification and release of most of the classified documents collected over the 50-year history of ORNL.

ORNL maintains systems to demonstrate ES&H performance through the tracking of hazardous materials, through a focus on pollution prevention, and through the implementation of new and reliable methods of waste storage and disposal. ORNL's goal is to establish effective measurement of performance systems and to maintain and monitor continuous improvement in ES&H.

7.3.1.2 • Target Milestones and Success Indicators

Consistent with the direction of the ES&H Management Planning Process described in DOE's FY 1998 ES&H Management Plan Guidance Manual, ORNL will focus on the development of target milestones and success indicators by which ES&H performance measures, objectives, and metrics can be established. This effort will be conducted in partnership with the DOE ORNL Site Office.

7.3.2 • Current Conditions

7.3.2.1 • Regulatory Environment

A Federal Facilities Agreement (FFA) among DOE, the State of Tennessee, and the Environmental Protection Agency provides a framework for actions to protect human health and the environment, achieve compliance with environmental regulations, and meet public expectations. Within the DOE-LMER management contract, ORNL has committed to several actions to improve its ES&H program and accepted specific responsibilities:

- ORNL has accepted oversight responsibility regarding health, safety, and environmental law compliance for the Laboratory and the National Environmental Research Park.
- ES&H activities conducted under the contract are subject to the Standards/Requirements Identification Document (S/RID) approved by DOE or to the "Work Smart" standards as approved by DOE.
- ORNL has committed to significant progress toward achieving DOE Voluntary Protection Program "STAR" status by 1998 and will report at least annually on its progress toward this commitment.
- The contract also specifies ORNL compliance with all the requirements of the Clean Air Act and Clean Water Act and with 19 other environmental laws and their applicable regulations; in addition, ORNL will assist DOE in compliance with other specified laws and executive orders, such as the National Environmental Policy Act (NEPA) and the Endangered Species Act.
- ES&H activities conducted under the contract are also subject to specified DOE policies and orders.

ORNL has begun the necessary and sufficient (N&S) process. The purpose of this process is to identify a set of ES&H "Work Smart" standards necessary to (1) ensure compliance with laws and regulations and (2) provide adequate protection to the environment, the workers, and the public at the lowest possible cost. Work is in progress to define the hazards associated with work conducted at ORNL as a primary basis for developing the set of "Work Smart" standards to be included in the Laboratory's management contract.

7.3.2.2 • Operating Context

The diversity of ORNL's R&D and support activities creates challenges as well as opportunities for the Laboratory in the effort to apply ES&H goals and objectives in a manner that supports the mission and adds value to operational performance. Established in 1943, ORNL has substantial ES&H legacy problems resulting from past operations. Today, it is engaged in basic and applied R&D in all of DOE's major businesses: science and technology, energy resources, national security, and environmental quality. Although significant changes in operations are not currently expected, ORNL management recognizes the need to focus on full integration of ES&H considerations into its mission and on the Laboratory's R&D competencies. Also of major importance is the need to institutionalize the budgeting prioritization process, taking into consideration both the risks of operation (to the environment, site personnel, and the public) and the need to effectively and efficiently conduct the activities necessary for mission execution.

With the expectation of decreasing ES&H funding and with the continuing emphasis on overhead reduction, ORNL is challenged to redefine approaches for providing a safe and compliant operating environment in which its mission may be accomplished more cost effectively. ES&H management planning, as described in the DOE Guidance Manual for FY 1998, is an emerging process at ORNL that must be integrated with other business planning processes. The redefinition of ORNL's relationships with other DOE facilities in Oak Ridge will also challenge program continuity and improvements. ORNL's affiliation with Lockheed Martin Energy Systems, Inc., is being defined to ensure continuation of services essential to both organizations. The evolving relationship with DOE under the new management contract requires that ORNL anticipate, define, and meet DOE expectations, supported by effective means of measuring and communicating its efforts.

7.3.3 • Policies, Organization, and Management

Under the DOE-LMER management contract, ORNL is placing strong emphasis on communication of ES&H expectations, integration of ES&H requirements in work activities, management of ES&H risks, and measurement of ES&H performance. The Laboratory's ES&H management program is structured to establish key roles and responsibilities for ES&H, ES&H ownership by line management, and accountability for ES&H performance. It is described in detail in the *Lockheed Martin Energy Research Corporation ES&H Management Plan for the Oak Ridge National Laboratory.*

7.3.3.1 • ORNL ES&H Program Approach

Organizational Structure

The Laboratory Associate Director for Operations, Environment, Safety, and Health (OES&H) is one of five associate directors reporting to the Laboratory Director. The Associate Director for OES&H is responsible for identifying the ES&H requirements applicable to ORNL research and operations and for developing programs to assure that these requirements are met. The OES&H directorate includes offices that administer

- comprehensive environment, safety, health, and quality (ESH&Q) guidance in the areas of radiation protection, industrial safety, industrial hygiene, nuclear criticality safety, operational readiness, facility safety, environmental compliance, and quality assurance;

- ORNL business management functions (see Sect. 7.2);
- medical services and maintenance support; and
- operations support in the areas of information management (see Sect. 6.4), waste management (see Sect. 7.4), engineering, and security.

Industrial safety, industrial hygiene, radiation protection, and quality assurance specialists from the OES&H directorate are assigned to specific R&D and operations divisions. Each of these divisions also selects staff members to serve as environmental protection, radiation control, and safety officers.

Key Roles and Responsibilities

Compliance with ES&H policies and requirements is the responsibility of each employee at ORNL. Members of ORNL line management are responsible for ensuring that research and operational activities are conducted in a manner that is protective of human health and the environment and for fully implementing ES&H policies and requirements within their organizations. The ORNL ES&H organizations assist the line organizations in determining the applicability of ES&H requirements, developing strategies to meet the requirements, and implementing the strategies. They also provide assistance in sampling, monitoring, record keeping, permitting, and assessing the impact of new or changing requirements. ES&H staff activities include

- preparing environmental protection, safety, and health directives;
- providing specialized technical guidance and assistance;
- providing a single point of contact for environmental regulatory interface;
- conducting ES&H surveillance activities;
- negotiating facility-wide environmental permits;
- providing environmental, industrial hygiene, and health physics monitoring;
- developing comprehensive Laboratory-wide ES&H programs; and
- conducting ES&H resource planning and prioritization.

Functional Policy Managers from each business, research, and ESH&Q functional organization are responsible for assessing the need for new policies, procedures, and guidance for their areas of responsibility and for developing impact and cost/benefit analyses to justify proposals for new guidance. The ORNL Directives Review Committee reviews and approves such proposals.

The ORNL ESH&Q Committee (ESHQC) is the decision-making body representing all of ORNL's directorates. With a membership consisting of high-level ORNL managers, the ESHQC approves implementation strategies for new ES&H requirements, coordinates ORNL's responses to requests for ES&H information, recommends resource allocations for special ES&H activities, and reviews ES&H performance by line organizations.

The associate directors of the Laboratory's research directorates annually review each division's ES&H goals and objectives with the ESHQC. This annual review ensures that overall ES&H goals are addressed by the research divisions at all levels.

Laboratory management reviews the results of internal assessments conducted by line and ES&H organizations and the findings from corporate audits, DOE appraisals, and other evaluations.

Accountability for ES&H Performance

Accountability for ES&H compliance is administered through the ORNL Positive Discipline Program. Guidelines have been developed and issued for use in cases involving noncompliance with ES&H requirements. Disciplinary actions have the objectives of achieving correction, where applicable, and providing constructive direction to ensure future compliance.

7.3.3.2 • Communication of ES&H Expectations

Communication of ES&H expectations takes place at several levels. The fundamental ES&H expectations of DOE are contained in the DOE-LMER management contract. The ES&H staff organizations interface with DOE and external regulators for guidance when interpreting the ES&H requirements stipulated in the management contract, DOE policies and orders, laws, regulations, and other technical guidance. Information from these interfaces is communicated to ORNL employees so that the requirements can be incorporated into their work. Tools for the communication of ES&H expectations to employees include strategic planning, policies and procedures, information bulletins, meetings, announcements, and training.

ORNL has established a new directives system to provide a consistent basis for development and implementation of policies, procedures, and requirements to ensure compliance with ESH&Q requirements. The system is administered by a Directives Coordinator who provides procedural guidance and technical assistance to ORNL employees. Approximately 480 ORNL directives constitute the current directives system; they are being made available on ORNL's World Wide Web pages.

A number of LMES procedures are still in use following the transition to LMER. The ORNL Directives Coordinator is directing a transition process to determine which of these procedures will need ORNL-specific modifications to improve their applicability to ORNL operations, thereby supporting ORNL's ability to comply with ESH&Q requirements.

It is ORNL's policy that employees will be provided the training to perform their jobs in a manner that protects workers and is compliant with environmental laws and regulations. The Laboratory continues to explore means of controlling ES&H training costs, with emphasis on improving the quality and efficiency of training. For example, special attention has been given to eliminating unnecessary requirements and allowing employees to demonstrate proficiency through testing.

7.3.3.3 • Integration of ES&H Requirements in Work Activities

Achieving excellence in implementing ES&H programs depends on the effective integration of management systems and the involvement of employees. ORNL promotes such integration and involvement in its work planning approach, in the execution of work activities, and in the use of specialized work teams.

Work Planning Approach

All employees are responsible for ensuring that ES&H issues are addressed before implementing or modifying research and operations activities and that ES&H requirements are met before modifying or operating new equipment and facilities. Employees work with division ES&H staff to initiate the NEPA process and to identify ES&H requirements in the

planning stages of all projects. Staff from the OES&H directorate assist the divisions in identifying requirements and developing compliance strategies. A safety and health component has been built into the NEPA process to ensure that all ES&H requirements are identified during the conceptual phase of a research project or activity. Meetings are held before all construction jobs to ensure that needed permits are in place, potential hazards have been identified, and other ES&H concerns have been addressed. Compliance with ES&H policies and requirements is also supported by interfaces between research, operations, and ES&H organization staff and the ORNL Operating Committee, which is responsible for assignment of General-Purpose Equipment (GPE)/General Plant Project (GPP) funds, when new equipment or modifications to existing equipment are required.

Through the N&S process, subject-matter experts, stakeholders, and others assess work to be performed and identify the policies, standards, and requirements needed to conduct the work safely. This process is in contrast to the application of all standards to all work, regardless of the nature of the work.

Execution of Work Activities

Divisional ES&H staff interact with division personnel to communicate and interpret ES&H requirements, assist in implementation of work strategies, and provide technical assistance and evaluation to ensure that engineered and administrative controls are applied effectively. Staff from the OES&H directorate provide support to ensure that research and operational activities are conducted in a manner compliant with applicable ES&H requirements. This approach supports the goal of minimizing the oversight responsibility of the ES&H organizations and maximizing their advisory and support function.

Specialized Work Teams

Specialized work teams are established to address specific ES&H issues. These teams include an Occupational Safety and Health Safety Response Team, co-sponsored by the ORNL Plant and Equipment Division and the OES&H directorate, which supplements the regular maintenance program by responding to requests arising from hazards that represent a "clear and present danger"; the Safety and Health Evaluation and Support Team, which provides comprehensive health and safety planning of activities that represent a significant portion of the hazardous operations and personnel risks at ORNL; and Safety and Health Task Teams, established as needed to address potential problems and specific concerns in response to employee suggestions, findings from assessment activities, or indications suggested by performance measures.

7.3.3.4 • Management of ES&H Risks

Each ES&H task funded by ORNL overhead is ranked on the basis of the risk and benefit associated with the task. Overhead resources are allocated within and between organizations using the results of this risk-based prioritization system, which is supportive of DOE's annual ES&H budget formulation and management planning process. The ORNL resource planning and prioritization process consists of (1) needs assessment and activity data sheet (ADS) preparation, (2) risk-based prioritization of activities and risk management decision making, and (3) ES&H budget formulation and development of top-level ES&H budget summaries (on an annual basis).

The ORNL ES&H staff is striving to build a close working relationship with the ES&H professionals in the DOE ORNL Site Office and the DOE Oak Ridge Operations Office. Further development of this relationship is expected to improve ES&H planning and budget submissions and ES&H execution plans and performance.

7.3.3.5 • Measurement of ES&H Performance

ES&H performance at ORNL is evaluated through performance measures—those included in the contract and secondary measures—and through a performance assessment program that involves three levels of assessment: self-assessment by line organizations, internal independent assessment (Director's Review Committee review or technical audit), and external assessment (conducted by Lockheed Martin Corporation, DOE, or federal or state regulators). ORNL uses the Energy Systems Action Management System (ESAMS) to track commitments and action items from external assessments. This system may also be used for tracking corrective actions from line organization self-assessments, which are developed and tracked at the division or office level.

7.3.4 • ES&H Plans and Initiatives

7.3.4.1 • Present ES&H Concerns

ORNL has one of the oldest physical plants in the DOE laboratory system, with a substantial legacy of ES&H problems that need correction. Several hundred sites at ORNL are contaminated with radionuclides and hazardous chemicals. There is also significant contamination of surface water, groundwater, and biota. Remediation and legacy waste management activities relating to these issues are described in Sect. 7.3.5.

Potential hazards arise from both radiological and nonradiological activities. As discussed in Sect. 7.6, ORNL operates one reactor, the High Flux Isotope Reactor; several other reactors have been permanently shut down and are awaiting transition to the decontamination and decommissioning program. Because of changing missions, several isotope production facilities have been shut down, and removal of radioactive materials from these facilities is in progress. Current operating missions include the processing of such radioisotopes as ^{252}Cf and ^{192}Ir and the storage of ^{233}U. In addition, over 35 facilities at ORNL are used for the temporary processing and storage of radioactive, chemical, and mixed hazardous wastes in gaseous, liquid, and solid forms. These facilities include burial grounds, storage buildings, surface impoundments (ponds or lagoons), surplus facilities, and underground storage tanks.

ORNL operates several accelerators and a variety of facilities for biological, energy, materials science, and neutron science R&D. Radiation protection for workers and the public is required for accelerators, X-ray units, sealed sources, and radioisotope production, handling, and use. Nonradiological hazards include electrical systems, hoisting and rigging operations, chemicals, biohazards, moving vehicles, construction activities, and natural phenomena such as severe weather.

7.3.4.2 • Plans for Ensuring ES&H Compliance

The *Lockheed Martin Energy Research Corporation ES&H Management Plan for the Oak Ridge National Laboratory* describes the approach used at ORNL to ensure the health

and safety of employees and the public, protect the environment, and comply with applicable DOE policies and orders and other ES&H requirements. The plan documents the systems and processes used by ORNL to (1) establish and communicate ES&H expectations to the ORNL community, (2) identify and secure funding for ES&H activities using risk-based planning and priority setting, (3) conduct R&D activities and operations through integration of ES&H principles in work planning and execution, and (4) assess ES&H performance and provide feedback to promote continuous improvement.

ORNL is developing an integrated approach to year-round ES&H planning. The intent is to ensure that activities and resources necessary to manage ES&H risks in the operation of ORNL and to achieve and maintain compliance with ES&H regulations are recognized and that adequate planning takes place. ORNL is developing ways to integrate the ES&H Management Planning Process and other site business planning processes.

The estimated cost of meeting all ES&H needs identified by ORNL for the ES&H Management Planning Process is presented in Table 7.4. Actual funding for future years has not been determined. Completion of the N&S process (see Sect. 7.3.2.1) will allow ORNL to determine appropriate requirements for satisfying "Work Smart" standards and to properly prioritize funding requests.

Significant areas of concern include infrastructure needs, nuclear criticality safety program support, National Pollution Discharge Elimination System (NPDES) compliance, industrial safety and industrial hygiene (especially hoisting and rigging, contractor safety, and electrical safety), transportation safety/vehicle fleet safety, Phase III of the Safety Analysis Reports Update Program (SARUP), and chemical safety.

ORNL's environmental management activities and plans are described in Sect. 7.3.5. Waste management and minimization activities and plans are described in Sect. 7.4.

7.3.5 • Environmental Management Activities

Environmental restoration and legacy waste management activities at ORNL are the line responsibility of the LMES Environmental Management and Enrichment Facilities organization's Environmental Restoration Division and Waste Management Organization.

The remedial action component of the Environmental Restoration Program addresses the investigation and remediation of the contaminated sites and contaminated environmental

Table 7.4
Estimated ES&H Management Plan funding requirements by fiscal year[a]
($ in thousands)

	1997	1998	1999	2000	2001	2002
Indirect	45,891	47,701	47,983	47,954	46,758	46,720
Operating[b]	41,682	42,247	13,707	12,794	13,059	8,919
Capital equipment	4,260	2,408	2,412	1,954	1,261	0
GPP[c]	420	1,250	8,150	2,750	450	450
Line item	0	0	5,000	14,089	9,200	0
Total funding requirement	92,253	93,606	77,252	79,541	70,728	56,089

[a]Does not include cost from LMES central organizations distributed to ORNL.
[b]Includes division administration as a direct operating expense.
[c]General Plant Project.

media at ORNL. Environmental data for remedial sites are collected in cooperation with other efforts at ORNL (e.g., the Environmental Compliance Program) with support from technical staff in the Environmental Sciences Division, Energy Division, and other ORNL organizations to address contaminant transport in the complex hydrogeologic setting at ORNL. Efforts to evaluate and remediate environmental problems build on research efforts at ORNL that are supported by DOE's Office of Energy Research and other basic science programs (see Sect. 5). The program also includes deactivation, surveillance and maintenance (S&M), and decontamination and decommissioning (D&D; here decommissioning is demolition or reuse) of contaminated surplus facilities.

The strategy for implementing the ORNL Environmental Restoration Program includes the following steps:

1. Sites are prioritized for rapid actions based on risk to human health and the environment. Rapid actions are taken to address contaminant releases and transport to off-site surface water and local groundwater. These must be consistent with likely future final actions. Monitoring at key locations quantifies and tracks contaminant releases and identifies major sources of contaminant release.
2. Remedial investigations are conducted to provide the information needed to formulate and implement final remedial actions. This step also includes working with stakeholders to establish land use objectives, conducting technology development activities, and performing feasibility studies.
3. Remediation is conducted to achieve the final goals for risk reduction and compliance with environmental regulations commensurate with planned or potential future land use.
4. Monitoring is continued at key locations to document the performance of remedial actions, evaluate the need for contingent actions, and identify remaining or new areas of concern.

Contaminated sites are prioritized for investigation and remediation on the basis of current and future risk to human health and the environment. Sites are prioritized for early actions based on potential off-site risk and for final actions based on potential future on-site risk to human health and the environment. Early actions for contaminant releases off site have been initially prioritized on the basis of the contribution to the risk from water ingestion at White Oak Dam. Early actions are then taken to rapidly reduce these contaminant releases. Final actions have been prioritized on the basis of future potential on-site risk. This prioritization was developed from contaminant inventories and potential hazard, and the ranking was modified by the potential for off-site release or on-site exposure resulting from failure of existing containment.

Some of ORNL's surplus facilities contain substantial amounts of residual radioactive material. Because radioactivity could be released to the environment, plans are for these facilities to undergo D&D. Until D&D is complete, facilities must be kept under surveillance to schedule any necessary maintenance and to ensure containment. The inventory of surplus contaminated facilities includes experimental reactors, technology support facilities, hot cells, isotope processing facilities, research laboratories, and decontamination facilities.

A structured program of S&M has been established to ensure adequate containment of residual radioactive and hazardous materials, to provide safety and security controls to minimize potential hazards to on-site personnel and the general public, and to cost-effectively manage surplus sites and facilities in compliance with applicable DOE orders. These objectives are met through a structured program of periodic surveillance and site inspections,

routine maintenance, and special projects to correct facility degradation or to eliminate facility-specific hazards.

The program includes the deactivation and stabilization of inactive ORNL facilities for acceptance into DOE's Environmental Restoration Program. The Isotope Facilities Deactivation Project manages the activities required to place 19 inactive isotope production facilities in a radiologically and industrially safe condition for acceptance into DOE's Environmental Restoration Program. Similarly, the High Ranking Facilities Deactivation Project will stabilize four other ORNL facilities, including the Bulk Shielding Reactor and the Tower Shielding Reactor. The goal of these projects is to place all facilities in a condition such that (1) all stored radioactive materials, high-level radioactive wastes, and contaminated liquid waste have been removed; (2) the structures and radiation-monitoring systems are in a physical condition adequate to contain and to monitor any radioactive contamination in accordance with DOE Order 5480.1; (3) security systems and procedures are adequate to prevent unauthorized entry; and (4) all hazardous chemicals have been removed.

The budget for decommissioning of surplus facilities is subject to annual reprioritization to reflect facility conditions and ES&H risks, integration with remedial action at adjacent sites, and available funding. Budget requests for decommissioning of prioritized facilities at ORNL are submitted annually and included in the DOE Environmental Management Five-Year Plan. The budget for decommissioning surplus facilities was approximately $12 million in FY 1995. During the planning period, budgets are expected to increase to keep pace with DOE's goals for site restoration. Near-term D&D projects will focus on removal of facilities in conjunction with regulatory-driven remediation of former waste management sites.

Table 7.5 provides the estimated funding requirements for environmental management for ORNL, based on input to the DOE Environmental Management Five-Year Plan. These estimates were developed through analysis of expected needs at the Laboratory. Actual funding for future years has not been determined.

Environmental restoration activities for FY 1996 include:

- continued monitoring and assessment of ORNL groundwater, surface water, and ecology,
- decision for the remediation of four radioactively contaminated surface water impoundments in the main plant area,
- demonstration of technologies for remote retrieval of radioactive sludges from large, 50-year-old underground storage tanks in the main plant area,
- action to mitigate ^{90}Sr releases from waste burial trenches in waste area grouping 4,
- completion of in situ vitrification of radioactively contaminated soils in pit 1 of waste area grouping 7,
- removal or closure of several small, inactive low-level liquid radioactive waste storage tanks,
- demolition of the inactive Waste Evaporator Facility,
- initiation of actions to remove 5000 gal of transuranic sludges from underground storage tanks at the old hydrofracture facility,
- plugging of wells that are conduits for contaminants moving from deep hydrofracture grout sheets to the near-surface water,
- deployment of a reactive gas removal system at the Molten Salt Reactor Experiment and continued planning for removal of uranium deposits and fuel salts,
- deactivation and stabilization of three isotope production facilities (Buildings 3028, 3029, and 7025), and

Table 7.5
Estimated Environmental Management Five-Year Plan funding requirements by fiscal year
($ in millions)[a]

	1996	1997	1998	1999	2000	2001	2002
Environmental Restoration[b]							
Operating	55.1	51.0	59.1	59.1	59.1	59.1	59.1
Capital equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	55.1	51.0	59.1	59.1	59.1	59.1	59.1
Nuclear Material and Facility Stabilization[c]							
Operating	13.4	14.6	2.8	2.8	2.8	2.8	2.8
Line item	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	13.4	14.6	2.8	2.8	2.8	2.8	2.8
Waste Management							
Operating	55.7	45.3	66.7	67.0	65.8	65.8	65.8
Capital equipment	0.8	1.2	0.4	0.4	0.4	0.4	0.4
Construction	14.7	10.1	3.1	0.0	0.0	0.0	0.0
Total	71.2	56.6	70.2	67.4	66.2	66.2	66.2
Other[c]							
Operating	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Capital equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Total EM funding	143.9	126.4	136.3	133.5	132.3	132.3	132.3

[a]Operating BA, capital equipment, construction, and proposed construction. These estimates reflect funding from LMES central organizations, excluding Technology Development (EW40).
[b]Costs for FY 1998–FY 2002 are estimates.
[c]Funding included in the ORNL Financial Plan.

- initiation of planning and preparations for defueling the Bulk Shielding Reactor and the Tower Shielding Reactor.

7.3.6 • Landlord Funded ES&H

The secretarial office responsible for Landlord activities at ORNL is the DOE Office of Energy Research (DOE-ER).

Significant reductions in funds for labor, materials, and services affecting ES&H programs occurred for FY 1995 and again for FY 1996. Additional reductions for FY 1997 will result in the elimination, deferral, or reduction in scope of some ES&H activities. Funding is allocated on the basis of risk prioritization scores, so the most significant impacts of reduced funding will be on activity data sheets (ADSs) representing either compliance activities or improvements to ES&H core programs. For a 10% reduction in funding of ES&H activities, affected activities will probably include target ADSs for the lowest-risk program improvements in ES&H activities, activities for replacing or upgrading equipment, and scheduled maintenance activities. An additional 5% reduction (i.e., a total reduction of 15%) could further slow upgrades and improvements.

7.4 • Waste Management

The Waste Management and Remedial Action Division (WMRAD) at ORNL is responsible for operation of all waste management facilities at ORNL (with the exception of the sanitary sewage system), as well as facility upgrades and construction of new waste management facilities. About 190 staff members are employed in the WMRAD. A number of other divisions and offices within ORNL and LMES provide support to WMRAD activities.

The waste management program at ORNL provides continuous collection, treatment, and discharge of gaseous wastes; treats 535 million liters (150 million gal) per year of liquid radioactive waste (excluding sewage); and manages about 6,200 m^3 (167,400 ft^3) per year of solid radioactive, hazardous, mixed, and sanitary/industrial wastes. Major waste management activities include comprehensive coordination of waste reduction; integrated strategic and long-range planning; upgrades of existing facilities and construction of new ones; performance assessments of solid waste storage areas and other waste disposal facilities; waste collection and certification; and waste treatment, storage, and disposal.

Expense funding for waste management activities in FY 1996 was about $50 million, not including $0.8 million for waste minimization (see Tables 7.5 and 7.6). The corrective activities component of the funding provides for implementation of the Federal Facilities Agreement (FFA) requirements as they pertain to active low-level liquid waste (LLLW) tanks and tank systems. It also includes upgrades of the Bethel Valley and Melton Valley LLLW collection and transfer systems. Line-item projects (see Sect. 7.5.1, "Site and Facilities") include three projects for implementation of the active LLLW tank systems requirements of the FFA and one project for construction of the Melton Valley Storage Tanks Capacity Increase Project.

Out-year activities in waste management include continued operation of waste treatment, storage, and disposal facilities, with several upgrades. Additional reservation-wide facilities for waste management will be added to promote efficiency and improved ES&H conditions. Waste reduction will continue to be emphasized.

The ORNL Pollution Prevention (P2) Program addresses all categories of waste generated at ORNL: sanitary/industrial, radioactive, hazardous, and mixed. The P2 Program performs the planning and reporting functions required by state and federal laws and DOE orders; provides coordination, training, and technical assistance to waste-generating divisions; provides funds (when available) to waste generators to help them reduce their waste generation; coordinates the sanitary waste recycling programs; spearheads affirmative procurement; runs an awards program; and tracks waste reduction. The P2 Program also

Table 7.6
Estimated Waste Minimization Plan funding requirements by fiscal year[a]
($ in thousands—BA)

	1996	1997	1998	1999	2000	2001	2002
Waste Management (EM70)	800	758	839	840	840	840	840
Energy Research[b]	0	530	539	549	559	549	549
Total	800	1288	1378	1389	1399	1389	1389

[a]Waste minimization funding is not included in the Waste Management costs in Table 7.5.
[b]Funding for FY 1996 was requested but not received.

administers a program of awareness for pollution prevention, as required by DOE Order 5400.1. Table 7.6 includes the funding requirements for the P2 Program.

Each ORNL division has a P2 representative who acts as the P2 Program's point of contact with that division. The P2 Program will pursue a strategy with the following essential features:

- Maintain an organization that comprises management and staff representatives who continue to develop and administer the program.
- Continue to identify materials, wastes, discharges, and emissions to be targeted for reduction.
- Continue to develop methods for tracking program performance and progress.
- Continue to foster and encourage the development of pollution prevention technologies, the awareness of environmental problems, and the philosophy that includes pollution prevention.

The strategy focuses on four major elements:

- the evaluation of research and support operations for pollution prevention opportunities and associated projects, including R&D,
- pollution prevention promotional activities,
- tracking activities (including wastes and pollution prevention projects), and
- the exchange of information and technology.

7.5 • Infrastructure and Support

7.5.1 • Site and Facilities

7.5.1.1 • Laboratory Description

ORNL's programs require a variety of buildings and equipment, including specialized experimental laboratories, a large complement of office space, and major utility and waste disposal facilities. The distribution of the Laboratory's space is presented in Table 7.7, and replacement plant value is presented in Table 7.8. The overall condition of the space is shown in Fig. 7.1, with a breakdown of use and condition in space in Fig. 7.2 and a summary of building age in Fig. 7.3.

As noted in Sect. 7.3, ORNL has one of the oldest physical plants in the DOE laboratory system. Continuing efforts are needed to enable extensive renovations and rehabilitation of general-purpose buildings and utility systems that have deteriorated owing to insufficient capital improvement funding for modernization and adaptation to changing program needs.

Increased DOE support for infrastructure improvements is improving the current situation. Several general-purpose office buildings have been constructed. A number of major construction line-item projects are in the design/construction phase, including roof replacement, steam distribution system upgrade, sanitary sewer upgrade, and process waste treatment system upgrade. Funding received through the Multiprogram Energy Laboratory Facilities Support (MEL-FS) program has been applied to infrastructure needs.

Table 7.7
ORNL space distribution

Location	Area (gross square feet)
ORNL main site (Bethel Valley and Melton Valley)	3,115,808
Oak Ridge Y-12 Plant	938,869
Oak Ridge K-25 Site	14,673
Leased off site	89,524

Table 7.8
Estimated replacement plant value[a]
(in millions of FY 1995 dollars)

Facilities type	Replacement cost range	
	Lower	Upper
Buildings and structures	818	1,156
Utility systems	269	392
All other	2,610	3,548

[a]DOE estimates the replacement value of ORNL facilities at $2.5 billion.

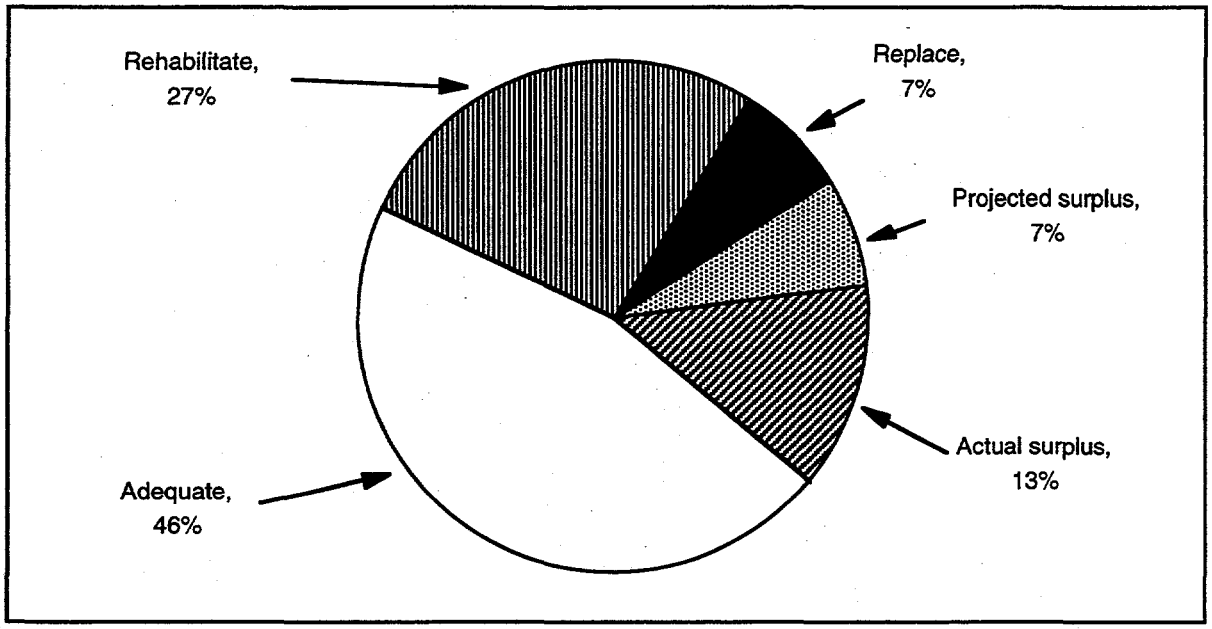


Figure 7.1
Condition of ORNL space. In the actual surplus category, 348,000 gross square feet (GSF) of the total 513,000 GSF is located at the Y-12 Plant.

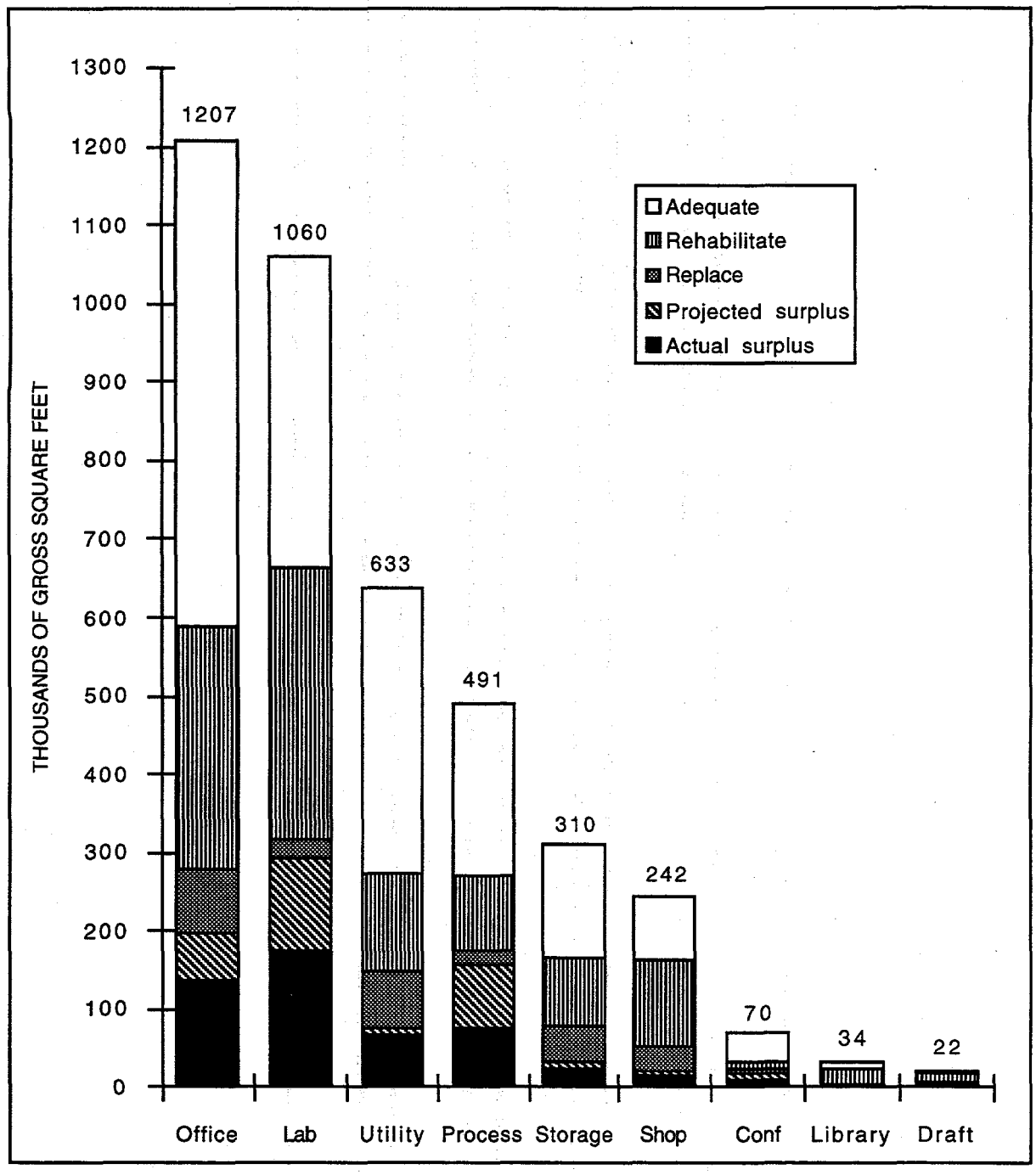


Figure 7.2
Use and condition of ORNL space, categorized by functional unit.

Additional funding is still needed to bring buildings and utilities up to acceptable standards. The need to use general-purpose equipment (GPE) funding to meet high-priority compliance requirements related to replacement of chlorofluorocarbons (CFCs) and underground storage tanks means that GPE funding is not available for other needs.

ORNL is committed to good stewardship of its resources, both in management of existing facilities and in planning for future needs. The cost of construction and upgrades is being addressed through increased interactions with the construction manager. The

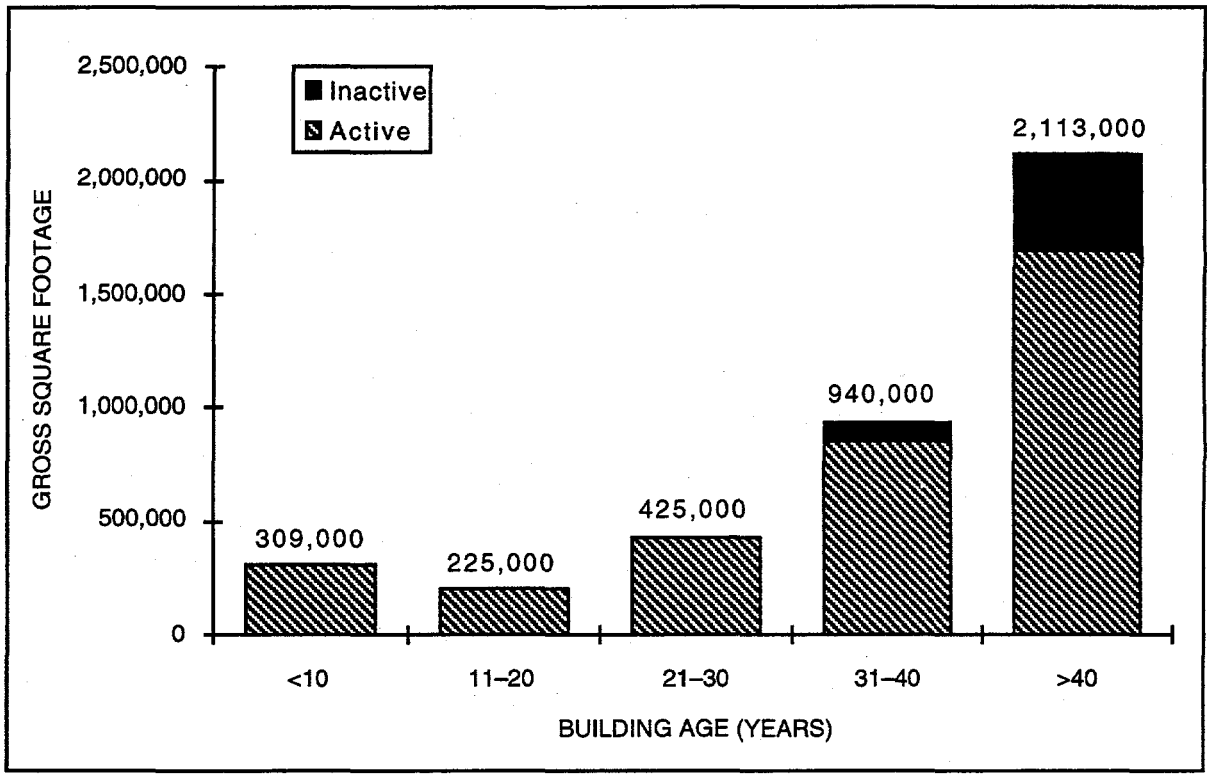


Figure 7.3
Age of ORNL buildings. Average age is ≈30 years. "Inactive" includes only actual surplus buildings. Of buildings over 40 years old, 348,000 GSF of the total 418,000 GSF of inactive space is located at the Y-12 Plant.

Laboratory will prioritize its needs and apply resources as they become available to ensure that maximum benefit is derived.

7.5.1.2 • Facilities Plans and Options

The Capital Assets Planning Group carries out capital asset management and facility planning for ORNL. This group develops the Integrated Facilities Plan (summarized in Appendix B) and site development plans. In addition, the Capital Assets Planning Group is ORNL's lead organization for DOE's Life-Cycle Asset Management process. The DOE MEL-FS program (see Sect. 5.1.1.7) has funded a pilot infrastructure management plan (IMP) process at ORNL. ORNL has prepared a draft IMP; the IMP and this section of the Institutional Plan serve as the primary documents to support planning and budgeting efforts in this area in FY 1996.

The ORNL Infrastructure Committee provides guidance and oversight in preparation of the IMP. The Capital Assets Manager is responsible for preparation of infrastructure activity data sheets (ADSs). Draft infrastructure ADSs are developed and priorities are assigned using the Capital Asset Management Process (CAMP) methodology. The ORNL Infrastructure Committee reviews draft infrastructure ADSs and concurs with the proposed project prioritization and budget.

The ORNL Operating Committee is responsible for assignment of GPE/General Plant Project (GPP) funds, when new equipment or modifications to existing equipment are required. Table 7.9 presents past and projected GPP and GPE requirements for ORNL.

General-Purpose Facilities

The objective of the IMP process is to provide a means for DOE facilities to report infrastructure planning and budgeting information in an integrated, timely, efficient, and consistent manner that will support the facility operating organization and DOE's budgetary needs and requests. The ORNL IMP is developed in accordance with the Infrastructure Management Guidance Document issued by the MEL-FS Program in February 1996. The information presented in the IMP is derived from a number of sources including the ORNL Institutional Plan, the Long-Range Maintenance Plan, DOE Office of Energy Research line-item project data sheets, management review data sheets for general plant projects, GPP equipment requests, condition assessment survey reports, and other relevant information.

The IMP process addresses the management functions needed to plan and budget all infrastructure support activities for the entire life cycle of all physical assets at ORNL and of ORNL facilities located at the Oak Ridge Y-12 Plant. This includes the acquisition of buildings and structures, major renovations of buildings and structures, purchase of equipment needed to support the performance of facility missions, and maintenance and repair of

Table 7.9
Past and projected GPP and GPE requirements for ORNL
(in thousands of dollars)

	1992	1993	1994	1995	1996	1997	1998
GPP funding							
Environmental Management							
EW3170	4,798						
EW20	2,552	140					
EX3170		7,500					
MEL-FS							
KG01			6,272	8,314			
Landlord							
KC03					1,290	7,645	10,010
Total	7,350	7,640	6,272	8,314	1,290	7,645	10,010
GPE funding							
Environmental Management							
EW	1,598						
EW35	1,402						
EX35		4,284					
MEL-FS							
KG			5,675	5,318			
Landlord							
35KC					3,310	9,262	10,255
Total	3,000	4,284	5,675	5,318	3,310	9,262	10,255

buildings, structures, or equipment. All infrastructure activities requiring program funding (for both programmatic and nonprogrammatic needs) are to be included in the IMP.

Projects in the IMP are identified from a number of sources, primarily the ORNL Long-Range Maintenance Plan. Projects are grouped on the basis of structural features or systems (e.g., roofing, electrical systems) and by use or area (e.g., nuclear, research, and support). Each infrastructure ADS is assigned a prioritized score using the CAMP process. Within infrastructure ADSs, individual activities are ranked so that available funding is committed to the most crucial needs across the Laboratory infrastructure.

Constraints on the availability of funding for infrastructure requirements make it difficult to address even the most crucial needs. The overall emphasis on reducing the federal budget also constrains line-item funding (as well as operational funding) and limits ORNL flexibility in addressing infrastructure requirements. Only the most urgent needs can be accommodated under these conditions.

As a result, the prioritization process for infrastructure projects is extremely important in the effort to optimize the use of available funds. A significant backlog of requirements in the areas of roofing replacement; building and site utility upgrades; heating, ventilation, and air conditioning system upgrades; and other basic infrastructure needs will continue to increase under current budgetary constraints.

Inactive Surplus Facilities

About 100 facilities at ORNL have been declared inactive or surplus because the programs for which they were built have ended. ORNL plans a vigorous program to manage and ultimately to renovate or dispose of facilities that have exceeded their useful life and that require continual surveillance and maintenance (S&M) to ensure safe shutdown. Funding for this program of renovation and disposal will be supplied by the DOE Office of Environmental Management and by the Inactive and Surplus Facilities subprogram (KG03) of the MEL-FS program. In FY 1995, this subprogram provided $160,000 to remove contaminated equipment and refurbish a machinery maintenance facility for reuse. No funding was provided for this subprogram in FY 1996, and funding in future years is uncertain.

Resource Requirements

The major initiatives described in Sect. 4 are among the resources needed to implement ORNL's strategic plan. Plans for construction supporting these initiatives and for other major construction projects are summarized in Table 7.10.

7.5.2 • Support Functions

As part of the reengineering effort described in Sect. 7.1, ORNL is analyzing many of its support functions, such as procurement, human resources, project planning and management, asset management, and research support services. Many of these functions have been provided by central organizations within Lockheed Martin Energy Systems, Inc. The focus of the reengineering efforts is to determine the most cost-effective and user-friendly systems, processes, and business rules that support ORNL operations. Reengineering will continue into FY 1997, with implementation to be completed by the start of FY 1998.

Table 7.10
Major construction projects[a]
($ in millions)

	Funded construction		Budgeted construction	Proposed construction					
	1995	1996	1997	1998	1999	2000	2001	2002	TEC[b]
Research program line-item projects									
National Spallation Neutron Source				6.0	60.0	139.0	203.0	260.0	1110.0
HFIR thermal neutron guide hall				5.1	14.8	2.7			22.6
HFIR remote handling facility					10.0				
Upgrade of molecular genetics facilities				10.0	15.0				25.0
Advanced Materials Characterization Laboratory						3.5	15.0	8.5	27.0
Accelerator and Reactor Improvements and Modifications	0.2	4.3	4.5	2.5	2.9	3.1			*c*
Waste management projects									
Bethel Valley LLLW-CAT[d] system upgrade (WBS 3.37)	13.9	3.0							60.9
Melton Valley LLLW-CAT system upgrade (WBS 3.45)	9.1								41.0
Bethel Valley FFA upgrades	7.0	0.3	1.1	1.9					13.8
MVST[e] capacity increase	21.4	11.0	6.3	1.2					48.0
General-purpose facility line-item projects									
Steam plant upgrade (boiler addition)				3.4	1.9				5.3
Replace deteriorated roofing[f]	0.2	2.1	0.0	4.0	6.6				16.0
Potable water system upgrade (6000 and 7000 areas)							6.5		6.5
Electrical systems upgrade						6.0			6.0
Coal Yard Runoff Treatment Facility upgrade					5.5				5.5
Fire alarm system upgrade							4.0	4.0	8.0

[a]Construction data as of September 1996.
[b]Total estimated cost.
[c]Individual projects; TEC not applicable.
[d]LLLW-CAT = low-level liquid waste collection and transfer.
[e]MVST = Melton Valley Storage Tanks.
[f]Total estimated cost includes $3.1 million from FY 1994.

7.6 • Laboratory Nuclear Operations

ORNL maintains an Office of Laboratory Nuclear Operations. The director of this office serves in an advisory capacity to the Laboratory Director. Reactor operations are conducted by the Laboratory's Research Reactors Division, which is part of the Advanced Materials, Physical, and Neutron Sciences directorate.

7.6.1 • Reactor Operations

The ORNL Research Reactors Division (RRD) oversees the operation, maintenance, and support of ORNL's research reactors so that they safely, reliably, and efficiently fulfill their intended functions in isotope production, research, and training. RRD works with 11 other ORNL divisions and organizations that either conduct reactor-based research or support reactor operations. Programmatic funding support is primarily received from DOE's Office of Energy Research (DOE-ER), and oversight is provided by the Office of Nuclear Energy, Science and Technology (DOE-NE) and the Oak Ridge Operations Office (DOE-ORO).

ORNL currently operates one Category A reactor, the High Flux Isotope Reactor (HFIR). Use of HFIR is expected to continue for neutron scattering studies for materials science, production of transplutonium isotopes, production of high-specific-activity radioisotopes (for medicine, industry, and research), materials irradiation, gas-cooled reactor fuel studies, and neutron activation analysis. These activities are described in Sect. 5.1.1.4.

Reactor operations staff use the principles of continuous improvement in initiating enhanced methods, processes, and procedures. Improved relations with users are being emphasized by establishing a reputation for reliability; projecting and adhering to forward-looking, 60-day operating schedules using the HFIR Users Committee to resolve competing demands; enhancing user indoctrination and training; and monitoring user satisfaction.

Near-term and interim spent fuel disposition solutions are also receiving priority attention pending the determination of final disposition arrangements by DOE. The GE-2000 shipping cask provides part of the solution. The addition of multiple-tier spent fuel storage silo clusters in the HFIR storage pools provides another part. Four silo clusters have been installed, and additional clusters will be fabricated and installed as needs and funding warrant. For the interim period between in-pool storage and final disposition, development of the capability for on-site dry storage is being pursued.

Two other ORNL reactors, the Bulk Shielding Reactor and the Tower Shielding Reactor, are included in the High Ranking Facilities Deactivation Project (see Sect. 7.3.5). One additional reactor, the Pool Critical Assembly, is in standby status.

7.6.2 • Nuclear Facilities

In addition to the HFIR, ORNL maintains a variety of nuclear facilities that support the Laboratory's R&D competency in neutron-based science and technology (see Sect. 2). These include hot cells and support cells that provide shielding to protect workers from penetrating radiation when radioactive materials are being received, processed, or packaged for off-site shipment. Activities for which these facilities are required include

- analysis of radioactive samples,
- packaging of waste for on-site storage or disposal,
- receipt of radioactive materials and packaging for on-site use,
- packaging of radioactive materials for off-site disposal, and
- response to upset nuclear fuel and radioactive material events.

Efforts are under way to identify the capabilities, facilities, and processes that are integral to ORNL's R&D competency in neutron science and technology and that support both current and planned activities, including the major laboratory initiative in neutron science described in Sect. 4.1. The development of a software package to support the long-term management of these capabilities, facilities, and processes is being studied.

8 • Resource Projections

The Laboratory's organization chart appears in the Appendix. Resource projections are presented in the following tables:

- Table 8.1, Laboratory funding summary,
- Table 8.2, Laboratory personnel summary,
- Table 8.3, funding by assistant secretarial level office,
- Table 8.4, personnel by assistant secretarial level office,
- Table 8.5, resources by program,
- Table 8.6, subcontracting and procurement, and
- Table 8.7, small and disadvantaged business procurement.

These projections are based on funding requested in the FY 1998 budget submission documents, with some adjustments based on interim guidance. Planning for construction funding has not been completed beyond FY 2001. The projections include some funding for construction that supports the major laboratory initiatives proposed in Sect. 4.

In Tables 8.1, 8.3, 8.5, and 8.7, resource projections for future years are presented in terms of budget authority (BA) funding in millions of dollars. New BA requests are calculated by adding estimates of outstanding commitments and prefinancing to the total cost and then subtracting the prior-year uncosted budget.

Subcontracting and procurement funding is reported in Table 8.6 as total obligated funds for each fiscal year.

Personnel projections in Tables 8.2, 8.4, and 8.5 are given as the number of full-time equivalent (FTE) employees. The current assignment of FTE employees will change as ORNL proceeds with the reengineering process described in Sect. 7.1.

Table 8.1
Laboratory funding summary by fiscal year
($ in millions—BA)

	1995	1996	1997	1998	1999	2000	2001	2002
DOE effort	493.6	431.1	513.1	535.6	535.6	535.6	535.6	535.6
Work for others	72.2	55.3	60.9	64.5	64.5	64.5	64.5	64.5
Total operating	565.8	486.4	574.0	600.1	600.1	600.1	600.1	600.1
Capital equipment	36.4	32.9	38.3	35.6	35.6	35.6	35.6	35.6
Construction	79.5	16.2	0.0	0.0	0.0	0.0	0.0	0.0
Total ORNL	681.7	535.5	612.3	635.7	635.7	635.7	635.7	635.7
Proposed construction	—	—	12.4	35.2	33.9	3.4	1.2	0.0
Total projected funding	—	—	624.7	670.9	669.6	639.1	636.9	635.7

Table 8.2
Laboratory personnel summary by fiscal year
[Full-time equivalent (FTE) employees]

	1995	1996	1997	1998	1999	2000	2001	2002
Technical personnel, direct DOE effort	1595.0	1531.2	1519.1	1534.1	1534.6	1534.6	1534.6	1534.6
Technical personnel, Work for Others	308.5	337.9	279.6	261.1	261.1	261.1	261.1	261.1
Total technical direct personnel	1903.5	1869.1	1798.7	1795.2	1795.7	1795.7	1795.7	1795.7
Other direct	415.2	358.8	411.0	404.5	404.0	404.0	404.0	404.0
Total direct personnel	2318.7	2227.9	2209.7	2199.7	2199.7	2199.7	2199.7	2199.7
Indirect personnel	2065.3	2150.0	1985.0	1985.0	1980.0	1980.0	1950.0	1950.0
Total ORNL personnel	4384.0	4377.9	4194.7	4184.7	4179.7	4179.7	4149.7	4149.7

Table 8.3
Funding by assistant secretarial level office by fiscal year
($ in millions—BA)

	1995	1996	1997	1998	1999	2000	2001	2002
Science and Technology Programs								
Office of Energy Research								
Operating expense	167.8	147.5	201.9	221.5	221.5	221.5	221.5	221.5
Capital equipment	14.3	21.7	33.2	27.6	27.6	27.6	27.6	27.6
Construction	9.9	16.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	10.8	33.2	33.9	3.4	1.2	0.0
Total	192.0	185.4	245.9	282.3	283.0	252.5	250.3	249.1
Energy Programs								
Office of Energy Efficiency and Renewable Energy								
Operating expense	88.2	60.0	92.7	98.3	98.3	98.3	98.3	98.3
Capital equipment	2.7	4.4	2.8	3.4	3.4	3.4	3.4	3.4
Construction	1.7	3.5	0.0	0.0	0.0	0.0	0.0	0.0
Total	92.6	67.9	95.5	101.7	101.7	101.7	101.7	101.7
Office of Nuclear Energy, Science and Technology								
Operating expense	19.5	16.7	22.8	22.1	22.1	22.1	22.1	22.1
Capital equipment	1.4	0.8	1.4	2.8	2.8	2.8	2.8	2.8
Total	20.9	17.5	24.2	24.9	24.9	24.9	24.9	24.9
Office of Fossil Energy								
Operating expense	8.8	7.3	10.3	10.6	10.6	10.6	10.6	10.6
Energy Information Administration								
Operating expense	0.2	0.0	0.3	0.2	0.2	0.2	0.2	0.2
National Security Programs								
Office of Defense Programs								
Operating expense	12.6	10.8	13.6	13.6	13.6	13.6	13.6	13.6
Capital equipment	2.3	5.8	0.5	1.3	1.3	1.3	1.3	1.3
Construction	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	1.6	2.0	0.0	0.0	0.0	0.0
Total	15.3	16.6	15.7	16.9	14.9	14.9	14.9	14.9
Office of Nonproliferation and National Security								
Operating expense	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3
Office of Fissile Materials Disposition								
Operating expense	4.3	4.0	5.7	6.2	6.2	6.2	6.2	6.2
Environmental Management Programs								
Office of Environmental Management								
Operating expense	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Civilian Radioactive Waste Management								
Operating expense	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Environment, Safety, and Health								
Operating expense	12.5	10.9	15.4	13.8	13.8	13.8	13.8	13.8
Capital equipment	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Total	12.5	10.9	15.4	13.9	13.9	13.9	13.9	13.9

Table 8.3
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Other DOE Programs								
Office of Policy, Planning and Program Evaluation								
Operating expense	1.2	0.4	1.0	1.0	1.0	1.0	1.0	1.0
Federal Energy Regulatory Commission								
Operating expense	0.6	0.0	1.2	0.6	0.6	0.6	0.6	0.6
Office of Human Resources and Administration								
Operating expense	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Economic Impact and Diversity								
Operating expense	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DOE funding from Lockheed Martin Energy Systems central organizations								
Operating expense	153.6	157.9	140.0	140.0	140.0	140.0	140.0	140.0
Capital equipment	2.6	(0.3)	0.0	0.0	0.0	0.0	0.0	0.0
Construction	45.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	201.4	157.6	140.0	140.0	140.0	140.0	140.0	140.0
Subtotal DOE Programs								
Operating expense	474.6	415.6	505.2	528.2	528.2	528.2	528.2	528.2
Capital equipment	23.3	32.4	37.9	35.2	35.2	35.2	35.2	35.2
Construction	79.5	16.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	12.4	35.2	33.9	3.4	1.2	0.0
Total	577.4	464.2	555.5	598.6	597.3	566.8	564.6	563.4
DOE Contractors and Operations Office								
Operating expense	18.3	14.4	7.3	7.1	7.1	7.1	7.1	7.1
Capital equipment	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	22.0	14.4	7.3	7.1	7.1	7.1	7.1	7.1
Cooperative R&D Agreements								
Operating expense	0.7	1.1	0.6	0.3	0.3	0.3	0.3	0.3
Total DOE Programs								
Operating expense	493.6	431.1	513.1	535.6	535.6	535.6	535.6	535.6
Capital equipment	27.0	32.4	37.9	35.2	35.2	35.2	35.2	35.2
Construction	79.5	16.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	12.4	35.2	33.9	3.4	1.2	0.0
Total	600.1	479.7	563.4	606.0	604.7	574.2	572.0	570.8
Work for others								
Nuclear Regulatory Commission								
Operating expense	16.3	13.3	13.8	13.4	13.4	13.4	13.4	13.4
Capital equipment	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	16.5	13.3	13.8	13.4	13.4	13.4	13.4	13.4
Department of Defense								
Operating expense	25.6	14.5	20.9	21.9	21.9	21.9	21.9	21.9
Capital equipment	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	34.3	14.5	20.9	21.9	21.9	21.9	21.9	21.9
National Aeronautics and Space Administration								
Operating expense	2.4	3.0	2.2	2.2	2.2	2.2	2.2	2.2
Department of Health and Human Services								
Operating expense	3.2	3.0	4.5	4.5	4.5	4.5	4.5	4.5

Table 8.3
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Environmental Protection Agency								
Operating expense	1.7	0.9	1.4	1.4	1.4	1.4	1.4	1.4
National Science Foundation								
Operating expense	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Federal Emergency Management Agency								
Operating expense	1.6	0.7	1.0	4.5	4.5	4.5	4.5	4.5
Capital equipment	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	1.6	1.2	1.1	4.6	4.6	4.6	4.6	4.6
Department of Transportation								
Operating expense	17.5	5.1	3.4	5.6	5.6	5.6	5.6	5.6
Capital equipment	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Total	17.8	5.5	3.7	5.9	5.9	5.9	5.9	5.9
Other Federal agencies								
Operating expense	(4.7)	2.3	6.0	4.8	4.8	4.8	4.8	4.8
Electric Power Research Institute								
Operating expense	1.4	1.8	0.9	0.4	0.4	0.4	0.4	0.4
Other nonfederal agencies								
Operating expense	7.2	10.6	6.8	5.8	5.8	5.8	5.8	5.8
Capital equipment	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7.4	10.6	6.8	5.8	5.8	5.8	5.8	5.8
Total Work for Others								
Operating expense	72.2	55.3	60.9	64.5	64.5	64.5	64.5	64.5
Capital equipment	9.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4
Total	81.6	55.8	61.3	64.9	64.9	64.9	64.9	64.9
Total Laboratory								
Operating expense	565.8	486.4	574.0	600.1	600.1	600.1	600.1	600.1
Capital equipment	36.4	32.9	38.3	35.6	35.6	35.6	35.6	35.6
Construction	79.5	16.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	12.4	35.2	33.9	3.4	1.2	0.0
Total	681.7	535.5	624.7	670.9	669.6	639.1	636.9	635.7

Table 8.4
Personnel by assistant secretarial level office by fiscal year
[Full-time equivalent (FTE) employees]

	1995	1996	1997	1998	1999	2000	2001	2002
Office of Energy Research								
Technical personnel	617.8	591.5	604.2	641.8	641.8	641.8	641.8	641.8
Other direct personnel	133.2	117.2	172.5	174.6	174.6	174.6	174.6	174.6
Total direct personnel	751.0	708.7	776.7	816.4	816.4	816.4	816.4	816.4
Office of Energy Efficiency and Renewable Energy								
Technical personnel	169.3	208.6	195.6	188.6	188.6	188.6	188.6	188.6
Other direct personnel	25.8	10.0	8.8	8.3	8.3	8.3	8.3	8.3
Total direct personnel	195.1	218.6	204.4	196.9	196.9	196.9	196.9	196.9
Office of Nuclear Energy, Science and Technology								
Technical personnel	59.6	54.5	71.8	69.7	69.7	69.7	69.7	69.7
Other direct personnel	21.2	30.1	33.3	34.4	34.4	34.4	34.4	34.4
Total direct personnel	80.8	84.6	105.1	104.1	104.1	104.1	104.1	104.1
Office of Fossil Energy								
Technical personnel	20.8	23.7	23.3	22.9	22.9	22.9	22.9	22.9
Other direct personnel	1.7	1.0	1.0	1.1	1.1	1.1	1.1	1.1
Total direct personnel	22.5	24.7	24.3	24.0	24.0	24.0	24.0	24.0
Energy Information Administration								
Technical personnel	1.3	1.9	0.5	0.4	0.4	0.4	0.4	0.4
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.4	1.9	0.5	0.4	0.4	0.4	0.4	0.4
Office of Defense Programs								
Technical personnel	33.6	20.8	19.8	19.8	19.8	19.8	19.8	19.8
Other direct personnel	14.9	22.6	25.3	21.8	21.8	21.8	21.8	21.8
Total direct personnel	48.5	43.4	45.1	41.6	41.6	41.6	41.6	41.6
Office of Nonproliferation and National Security								
Technical personnel	0.0	0.6	0.3	0.4	0.4	0.4	0.4	0.4
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.0	0.6	0.3	0.4	0.4	0.4	0.4	0.4
Office of Fissile Materials Disposition								
Technical personnel	15.8	16.0	21.4	23.0	23.0	23.0	23.0	23.0
Other direct personnel	0.6	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total direct personnel	16.4	16.8	22.2	23.8	23.8	23.8	23.8	23.8
Office of Environmental Management								
Technical personnel	33.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	33.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Civilian Radioactive Waste Management								
Technical personnel	2.3	0.5	0.3	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.3	0.5	0.3	0.0	0.0	0.0	0.0	0.0
Office of Environment, Safety, and Health								
Technical personnel	27.6	36.6	41.7	36.6	36.6	36.0	36.0	36.0
Other direct personnel	3.5	2.7	2.8	2.2	2.2	2.2	2.2	2.2
Total direct personnel	31.1	39.3	44.5	38.2	38.2	38.2	38.2	38.2

Table 8.4
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Office of Human Resources and Administration								
Technical personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Policy, Planning and Program Evaluation								
Technical personnel	5.3	5.6	4.6	4.4	4.4	4.4	4.4	4.4
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	5.4	5.6	4.6	4.4	4.4	4.4	4.4	4.4
Federal Energy Regulatory Commission								
Technical personnel	5.0	10.0	5.9	4.2	4.2	4.2	4.2	4.2
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	5.0	10.0	5.9	4.2	4.2	4.2	4.2	4.2
Office of Economic Impact and Diversity								
Technical personnel	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
DOE funding from Energy Systems central organizations								
Technical personnel	540.1	507.2	497.3	498.4	498.4	498.4	498.4	498.4
Other direct personnel	180.0	160.7	156.6	156.6	156.6	156.6	156.6	156.6
Total direct personnel	720.1	667.9	653.9	655.0	655.0	655.0	655.0	655.0
Subtotal DOE Programs								
Technical personnel	1532.6	1478.0	1486.7	1509.6	1509.6	1509.6	1509.6	1509.6
Other direct personnel	381.9	345.1	401.1	399.8	399.8	399.8	399.8	399.8
Total direct personnel	1914.5	1823.1	1887.8	1909.4	1909.4	1909.4	1909.4	1909.4
DOE Contractors and Operations Office								
Technical personnel	59.9	49.1	31.1	23.9	24.4	24.4	24.4	24.4
Other direct personnel	12.3	4.6	1.1	0.5	0.0	0.0	0.0	0.0
Total direct personnel	72.2	53.7	32.2	24.4	24.4	24.4	24.4	24.4
Cooperative R&D Agreements								
Technical personnel	2.5	4.1	1.3	0.6	0.6	0.6	0.6	0.6
Other direct personnel	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.6	4.1	1.4	0.6	0.6	0.6	0.6	0.6
Total DOE Programs								
Technical personnel	1595.0	1531.2	1519.1	1534.1	1534.6	1534.6	1534.6	1534.6
Other direct personnel	394.3	349.7	402.2	400.3	399.8	399.8	399.8	399.8
Total direct personnel	1989.3	1880.9	1921.3	1934.4	1934.4	1934.4	1934.4	1934.4
Work for others								
Nuclear Regulatory Commission								
Technical personnel	82.3	75.3	67.9	68.5	68.5	68.5	68.5	68.5
Other direct personnel	4.4	2.5	2.1	1.5	1.5	1.5	1.5	1.5
Total direct personnel	86.7	77.8	70.0	70.0	70.0	70.0	70.0	70.0
Department of Defense								
Technical personnel	117.9	98.3	95.7	88.3	88.3	88.3	88.3	88.3
Other direct personnel	10.5	0.6	0.3	0.2	0.2	0.2	0.2	0.2
Total direct personnel	128.4	98.9	96.0	88.5	88.5	88.5	88.5	88.5

Table 8.4
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
National Aeronautics and Space Administration								
Technical personnel	7.6	9.4	8.2	7.0	7.0	7.0	7.0	7.0
Other direct personnel	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total direct personnel	8.2	9.7	8.5	7.3	7.3	7.3	7.3	7.3
Department of Health and Human Services								
Technical personnel	15.9	23.8	19.3	18.8	18.3	18.3	18.3	18.3
Other direct personnel	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel	16.0	23.9	19.4	18.4	18.4	18.4	18.4	18.4
Environmental Protection Agency								
Technical personnel	15.0	15.5	8.7	8.4	8.4	8.4	8.4	8.4
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	15.1	15.5	8.7	8.4	8.4	8.4	8.4	8.4
National Science Foundation								
Technical personnel	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Federal Emergency Management Agency								
Technical personnel	3.3	5.0	2.4	13.2	13.2	13.2	13.2	13.2
Other direct personnel	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	3.9	5.0	2.4	13.2	13.2	13.2	13.2	13.2
Department of Transportation								
Technical personnel	25.0	43.0	28.6	21.6	21.6	21.6	21.6	21.6
Other direct personnel	1.1	2.0	2.0	1.0	1.0	1.0	1.0	1.0
Total direct personnel	26.1	45.0	30.6	22.6	22.6	22.6	22.6	22.6
Other Federal agencies								
Technical personnel	13.5	22.7	22.8	19.9	19.9	19.9	19.9	19.9
Other direct personnel	0.9	2.1	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	14.4	24.8	22.8	19.9	19.9	19.9	19.9	19.9
Electric Power Research Institute								
Technical personnel	6.2	6.2	3.9	1.9	1.9	1.9	1.9	1.9
Other direct personnel	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel	6.4	6.3	4.0	2.0	2.0	2.0	2.0	2.0
Other nonfederal agencies								
Technical personnel	21.4	38.7	22.1	14.0	14.0	14.0	14.0	14.0
Other direct personnel	2.4	1.4	3.8	1.0	1.0	1.0	1.0	1.0
Total direct personnel	23.8	40.1	25.9	15.0	15.0	15.0	15.0	15.0
Total Work for Others								
Technical personnel	308.5	337.9	279.6	261.1	261.1	261.1	261.1	261.1
Other direct personnel	20.9	9.1	8.7	4.2	4.2	4.2	4.2	4.2
Total direct personnel	329.4	347.0	288.3	265.3	265.3	265.3	265.3	265.3
Total ORNL								
Technical personnel	1903.5	1869.1	1798.7	1795.2	1795.7	1795.7	1795.7	1795.7
Other direct personnel	415.2	358.8	410.9	404.5	404.0	404.0	404.0	404.0
Total ORNL direct personnel	2318.7	2227.9	2209.7	2199.7	2199.7	2199.7	2199.7	2199.7
Total ORNL indirect personnel	2065.3	2150.0	1985.0	1985.0	1980.0	1980.0	1950.0	1950.0
Total ORNL personnel	4384.0	4377.9	4194.7	4184.7	4179.7	4179.7	4149.7	4149.7

Table 8.5
Resources by program by fiscal year
($ in millions)

	1995	1996	1997	1998	1999	2000	2001	2002
Office of Energy Research								
Magnetic Fusion—AT								
Total operating	27.1	21.0	23.1	22.0	22.0	22.0	22.0	22.0
Capital equipment	1.0	0.1	0.4	0.4	0.4	0.4	0.4	0.4
Total program	28.1	21.1	23.5	22.4	22.4	22.4	22.4	22.4
Technical personnel	97.1	70.3	71.2	67.1	67.1	67.1	67.1	67.1
Other direct personnel	15.5	22.1	18.5	18.1	18.1	18.1	18.1	18.1
Total direct personnel	112.6	92.4	89.7	85.2	85.2	85.2	85.2	85.2
High Energy Physics—KA								
Total operating	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Capital equipment	0.1	0.3	0.2	0.2	0.2	0.2	0.2	0.2
Total program	0.4	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Technical personnel	1.7	1.6	1.5	1.5	1.5	1.5	1.5	1.5
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.7	1.6	1.5	1.5	1.5	1.5	1.5	1.5
Nuclear Physics—KB								
Total operating	10.6	11.3	14.7	15.0	15.0	15.0	15.0	15.0
Capital equipment	1.6	1.3	2.4	2.4	2.4	2.4	2.4	2.4
Construction	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	0.7	0.7	0.0	0.0	0.0	0.0
Total program	12.4	13.0	17.8	18.1	17.4	17.4	17.4	17.4
Technical personnel	46.1	52.1	60.7	60.7	60.7	60.7	60.7	60.7
Other direct personnel	12.7	4.9	7.1	7.1	7.1	7.1	7.1	7.1
Total direct personnel	58.8	57.0	67.8	67.8	67.8	67.8	67.8	67.8
Basic Energy Sciences—KC								
Total operating	78.0	86.7	107.9	129.6	129.6	129.6	129.6	129.6
Capital equipment	5.4	15.2	28.6	21.9	21.9	21.9	21.9	21.9
Construction	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	10.1	15.1	10.4	3.4	1.2	0.0
Total program	83.4	108.3	146.6	166.6	161.9	154.9	152.7	151.5
Technical personnel	273.0	316.3	309.1	361.0	361.0	361.0	361.0	361.0
Other direct personnel	71.4	72.4	84.6	102.9	102.9	102.9	102.9	102.9
Total direct personnel	344.4	388.7	393.7	463.9	463.9	463.9	463.9	463.9
Energy Research Analyses—KD								
Total operating	0.6	0.2	0.7	1.0	1.0	1.0	1.0	1.0
Technical personnel	2.6	1.7	1.4	1.4	1.4	1.4	1.4	1.4
Other direct personnel	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.7	1.8	1.4	1.4	1.4	1.4	1.4	1.4
Advanced Neutron Source—KE								
Total operating	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	54.9	10.3	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	65.9	10.3	0.0	0.0	0.0	0.0	0.0	0.0

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Multiprogram Energy Laboratory—Facility Support—KG								
Total operating	2.5	2.0	26.5	23.9	23.9	23.9	23.9	23.9
Capital equipment	5.5	4.2	0.0	0.0	0.0	0.0	0.0	0.0
Construction (MGPF)	9.7	9.4	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	0.0	7.4	8.5	0.0	0.0	0.0
Total program	17.7	15.6	26.5	31.3	32.4	23.9	23.9	23.9
Technical personnel	19.6	4.6	60.6	49.9	49.9	49.9	49.9	49.9
Other direct personnel	15.0	11.9	60.6	45.8	45.8	45.8	45.8	45.8
Total direct personnel	34.6	16.5	120.0	95.7	95.7	95.7	95.7	95.7
Biological and Environmental Research—KP								
Total operating	23.5	22.3	25.2	26.1	26.1	26.1	26.1	26.1
Capital equipment	0.7	0.6	1.6	2.7	2.7	2.7	2.7	2.7
Proposed construction	0.0	0.0	0.0	10.0	15.0	0.0	0.0	0.0
Total program	24.2	22.9	26.8	38.8	43.8	28.8	28.8	28.8
Technical personnel	89.9	88.4	86.5	86.0	86.0	86.0	86.0	86.0
Other direct personnel	4.4	1.9	2.2	0.7	0.7	0.7	0.7	0.7
Total direct personnel	94.3	90.3	88.7	86.7	86.7	86.7	86.7	86.7
Superconducting Super Collider—KS								
Total operating	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
University & Science Education—KT								
Total operating	1.6	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	2.6	5.4	2.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.7	5.4	2.0	0.0	0.0	0.0	0.0	0.0
Technology Transfer—KU								
Total operating	10.7	2.7	3.5	3.6	3.6	3.6	3.6	3.6
Technical personnel	29.2	40.8	11.8	14.2	14.2	14.2	14.2	14.2
Other direct personnel	3.0	0.9	0.1	0.0	0.0	0.0	0.0	0.0
Total direct personnel	32.2	41.7	11.9	14.2	14.2	14.2	14.2	14.2
University & Science Education—KV								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Office of Energy Research								
Operating expense	167.8	147.5	201.9	221.5	221.5	221.5	221.5	221.5
Capital equipment	14.3	21.7	33.2	27.6	27.6	27.6	27.6	27.6
Construction	9.9	16.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	10.8	33.2	33.9	3.4	1.2	0.0
Total program	192.0	185.4	245.9	282.3	283.0	252.5	250.3	249.1
Technical personnel	617.8	591.5	604.2	641.8	641.8	641.8	641.8	641.8
Other direct personnel	133.2	117.2	172.5	174.6	174.6	174.6	174.6	174.6
Total direct personnel	751.0	708.7	776.7	816.4	816.4	816.4	816.4	816.4

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Office of Nuclear Energy, Science and Technology								
Nuclear Energy R&D—AF								
Total operating	7.9	4.6	10.8	9.7	9.7	9.7	9.7	9.7
Capital equipment	1.1	0.4	1.1	2.5	2.5	2.5	2.5	2.5
Total program	9.0	5.0	11.9	12.2	12.2	12.2	12.2	12.2
Technical personnel	29.1	21.8	39.7	38.8	38.8	38.8	38.8	38.8
Other direct personnel	8.0	4.8	8.0	9.1	9.1	9.1	9.1	9.1
Total direct personnel	37.1	26.6	47.7	47.9	47.9	47.9	47.9	47.9
Naval Reactors—AJ								
Total operating	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Technical personnel	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Uranium Enrichment—CD								
Total operating	2.0	1.1	1.0	1.2	1.2	1.2	1.2	1.2
Capital equipment	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	2.2	1.1	1.0	1.2	1.2	1.2	1.2	1.2
Technical personnel	0.6	4.6	5.0	3.8	3.8	3.8	3.8	3.8
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.6	4.6	5.0	3.8	3.8	3.8	3.8	3.8
Policy and Management—Nuclear Energy—KK								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Isotope Production and Distribution Program—ST								
Total operating	9.5	10.9	10.9	11.1	11.1	11.1	11.1	11.1
Capital equipment	0.1	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Total program	9.6	11.3	11.2	11.4	11.4	11.4	11.4	11.4
Technical personnel	29.1	26.6	26.6	26.6	26.6	26.6	26.6	26.6
Other direct personnel	13.2	25.3	25.3	25.3	25.3	25.3	25.3	25.3
Total direct personnel	42.3	51.9	51.9	51.9	51.9	51.9	51.9	51.9
Total Office of Nuclear Energy, Science and Technology								
Operating expense	19.5	16.7	22.8	22.1	22.1	22.1	22.1	22.1
Capital equipment	1.4	0.8	1.4	2.8	2.8	2.8	2.8	2.8
Total program	20.9	17.5	24.2	24.9	24.9	24.9	24.9	24.9
Technical personnel	59.6	54.5	71.8	69.7	69.7	69.7	69.7	69.7
Other direct personnel	21.2	30.1	33.3	34.4	34.4	34.4	34.4	34.4
Total direct personnel	80.8	84.6	105.1	104.1	104.1	104.1	104.1	104.1
Office of Energy Efficiency and Renewable Energy								
Electric Energy Systems—AK								
Total operating	12.5	7.3	13.0	14.4	14.4	14.4	14.4	14.4
Capital equipment	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5
Total program	12.5	7.3	13.0	14.9	14.9	14.9	14.9	14.9
Technical personnel	26.0	28.2	27.5	23.5	23.5	23.5	23.5	23.5
Other direct personnel	2.3	1.7	1.4	1.7	1.7	1.7	1.7	1.7
Total direct personnel	28.3	29.9	28.9	25.2	25.2	25.2	25.2	25.2

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Geothermal Energy —AM								
Total operating	(0.7)	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Capital equipment	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Total program	(0.7)	0.7	0.8	0.8	0.8	0.8	0.8	0.8
Technical personnel	0.3	2.6	2.5	2.4	2.4	2.4	2.4	2.4
Other direct personnel	0.0	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total direct personnel	0.3	2.9	2.8	2.7	2.7	2.7	2.7	2.7
Hydrogen Research—AR								
Total operating	0.4	0.5	0.9	0.8	0.8	0.8	0.8	0.8
Technical personnel	2.8	2.6	2.5	2.5	2.5	2.5	2.5	2.5
Other direct personnel	0.1	0.0	0.6	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.9	2.6	3.1	2.5	2.5	2.5	2.5	2.5
Hydropower—CE								
Total operating	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Technical personnel	0.6	1.4	0.8	0.8	0.8	0.8	0.8	0.8
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.6	1.4	0.8	0.8	0.8	0.8	0.8	0.8
Solar Energy—EB								
Total operating	4.8	5.2	6.9	6.8	6.8	6.8	6.8	6.8
Capital equipment	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Total program	5.0	5.4	7.1	6.9	6.9	6.9	6.9	6.9
Technical personnel	11.7	13.9	15.4	15.4	15.4	15.4	15.4	15.4
Other direct personnel	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel	12.6	14.0	15.5	15.5	15.5	15.5	15.5	15.5
Buildings Sector—EC								
Total operating	18.4	12.5	16.2	16.4	16.4	16.4	16.4	16.4
Capital equipment	0.7	1.6	0.5	0.4	0.4	0.4	0.4	0.4
Total program	19.1	14.1	16.7	16.8	16.8	16.8	16.8	16.8
Technical personnel	32.5	40.8	38.5	37.8	37.8	37.8	37.8	37.8
Other direct personnel	4.5	2.9	1.5	1.1	1.1	1.1	1.1	1.1
Total direct personnel	37.0	43.7	40.0	38.9	38.9	38.9	38.9	38.9
Industrial Sector—ED								
Total operating	14.7	12.4	16.7	16.5	16.5	16.5	16.5	16.5
Capital equipment	1.4	1.0	0.5	0.0	0.0	0.0	0.0	0.0
Total program	16.1	13.4	17.2	16.5	16.5	16.5	16.5	16.5
Technical personnel	31.1	40.5	38.1	36.1	36.1	36.1	36.1	36.1
Other direct personnel	6.7	1.6	1.2	1.0	1.0	1.0	1.0	1.0
Total direct personnel	37.8	42.1	39.3	37.1	37.1	37.1	37.1	37.1
Transportation Sector—EE								
Total operating	34.9	20.3	36.4	40.7	40.7	40.7	40.7	40.7
Capital equipment	0.4	1.6	1.5	2.3	2.3	2.3	2.3	2.3
Total program	35.3	21.9	37.9	43.0	43.0	43.0	43.0	43.0
Technical personnel	52.2	62.7	64.1	63.7	63.7	63.7	63.7	63.7
Other direct personnel	10.1	3.4	3.7	4.1	4.1	4.1	4.1	4.1
Total direct personnel	62.3	66.1	67.8	67.8	67.8	67.8	67.8	67.8

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Technical and Financial Assistance—EF								
Total operating	1.7	1.0	1.7	1.8	1.8	1.8	1.8	1.8
Technical personnel	5.8	8.8	6.2	6.4	6.4	6.4	6.4	6.4
Other direct personnel	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	6.7	8.8	6.2	6.4	6.4	6.4	6.4	6.4
Policy and Management—EH								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Utility Sector—EK								
Total operating	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	6.3	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	6.4	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Policy and Management—KK								
Total operating	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Technical personnel	0.0	1.1	0.4	0.4	0.4	0.4	0.4	0.4
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.0	1.1	0.4	0.4	0.4	0.4	0.4	0.4
In-House Energy Management—WB								
Total operating	0.4	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Construction	1.7	3.5	0.0	0.0	0.0	0.0	0.0	0.0
Total program	2.1	3.5	0.0	0.1	0.1	0.1	0.1	0.1
Technical personnel	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	5.8	1.9	0.1	0.3	0.3	0.3	0.3	0.3
Total direct personnel	9.8	1.9	0.1	0.3	0.3	0.3	0.3	0.3
Total Office of Energy Efficiency and Renewable Energy								
Operating expense	88.2	60.0	92.7	98.3	98.3	98.3	98.3	98.3
Capital equipment	2.7	4.4	2.8	3.4	3.4	3.4	3.4	3.4
Construction	1.7	3.5	0.0	0.0	0.0	0.0	0.0	0.0
Total	92.6	67.9	95.5	101.7	101.7	101.7	101.7	101.7
Technical personnel	169.3	208.6	195.6	188.6	188.6	188.6	188.6	188.6
Other direct personnel	25.8	10.0	8.8	8.3	8.3	8.3	8.3	8.3
Total direct personnel	195.1	218.6	204.4	196.9	196.9	196.9	196.9	196.9
Office of Fossil Energy								
Coal—AA								
Total operating	6.7	5.7	6.8	7.0	7.0	7.0	7.0	7.0
Technical personnel	17.0	16.1	15.2	15.2	15.2	15.2	15.2	15.2
Other direct personnel	1.4	1.0	1.0	1.1	1.1	1.1	1.1	1.1
Total direct personnel	18.4	17.1	16.2	16.3	16.3	16.3	16.3	16.3
Gas—AB								
Total operating	1.0	1.3	2.1	1.9	1.9	1.9	1.9	1.9
Technical personnel	0.5	1.1	1.0	0.9	0.9	0.9	0.9	0.9
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.5	1.1	1.0	0.9	0.9	0.9	0.9	0.9

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Petroleum—AC								
Total operating	0.8	0.3	1.1	1.1	1.1	1.1	1.1	1.1
Technical personnel	1.7	3.4	3.6	3.6	3.6	3.6	3.6	3.6
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.8	3.4	3.6	3.6	3.6	3.6	3.6	3.6
Fossil Energy Environmental Restoration—AW								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Innovative Clean Coal Technology—AZ								
Total operating	0.2	(0.1)	0.1	0.3	0.3	0.3	0.3	0.3
Technical personnel	0.7	2.1	2.5	2.2	2.2	2.2	2.2	2.2
Other direct personnel	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.9	2.1	2.5	2.2	2.2	2.2	2.2	2.2
Strategic Petroleum Reserve—SA								
Total operating	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.3
Technical personnel	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total Office of Fossil Energy								
Total operating	8.8	7.3	10.3	10.6	10.6	10.6	10.6	10.6
Technical personnel	20.8	23.7	23.3	22.9	22.9	22.9	22.9	22.9
Other direct personnel	1.7	1.0	1.0	1.1	1.1	1.1	1.1	1.1
Total direct personnel	22.5	24.7	24.3	24.0	24.0	24.0	24.0	24.0
Energy Information Administration								
National Energy Information System—TA								
Total operating	0.2	0.0	0.3	0.2	0.2	0.2	0.2	0.2
Technical personnel	1.3	1.9	0.5	0.4	0.4	0.4	0.4	0.4
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.4	1.9	0.5	0.4	0.4	0.4	0.4	0.4
Total Energy Information Administration								
Operating expense	0.2	0.0	0.3	0.2	0.2	0.2	0.2	0.2
Technical personnel	1.3	1.9	0.5	0.4	0.4	0.4	0.4	0.4
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.4	1.9	0.5	0.4	0.4	0.4	0.4	0.4
Office of Defense Programs								
Weapons Activities—DP								
Total operating	0.0	10.8	13.6	13.6	13.6	13.6	13.6	13.6
Capital equipment	0.0	5.8	0.5	1.3	1.3	1.3	1.3	1.3
Proposed construction	0.0	0.0	1.6	2.0	0.0	0.0	0.0	0.0
Total program	0.0	16.6	15.7	16.9	14.9	14.9	14.9	14.9
Technical personnel	0.0	20.8	19.8	19.8	19.8	19.8	19.8	19.8
Other direct personnel	0.0	22.6	25.3	21.8	21.8	21.8	21.8	21.8
Total direct personnel	0.0	43.4	45.1	41.6	41.6	41.6	41.6	41.6

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Weapons Activities—GB								
Total operating	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	3.0	3.0	2.3	2.2	2.2	2.2	2.2	2.2
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Materials Production—GE								
Total operating	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Capital equipment	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	30.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	14.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	45.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New Production Reactors—NP								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Capital equipment	(0.1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	(0.1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Office of Defense Programs								
Total operating	12.6	10.8	13.6	13.6	13.6	13.6	13.6	13.6
Capital equipment	2.3	5.8	0.5	1.3	0.3	0.3	0.3	0.3
Construction	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	1.6	2.0	0.0	0.0	0.0	0.0
Total program	15.3	16.6	15.7	16.9	14.9	14.9	14.9	14.9
Technical personnel	33.6	20.8	19.8	19.8	19.8	19.8	19.8	19.8
Other direct personnel	14.9	22.6	25.3	21.8	21.8	21.8	21.8	21.8
Total direct personnel	48.5	43.4	45.1	41.6	41.6	41.6	41.6	41.6
Office of Environmental Management								
Environmental Restoration and Waste Management—Defense—EW								
Total operating	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Environmental Restoration and Waste Management—Non-Defense—EX								
Total operating	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	23.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	27.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	23.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	24.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Total Office of Environmental Management								
Total operating	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	33.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	33.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Fissile Materials Disposition								
Fissile Materials Disposition—GA								
Total operating	4.3	4.0	5.7	6.2	6.2	6.2	6.2	6.2
Technical personnel	15.8	16.0	21.4	23.0	23.0	23.0	23.0	23.0
Other direct personnel	0.6	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total direct personnel	16.4	16.8	22.2	23.8	23.8	23.8	23.8	23.8
Total Office of Fissile Materials Disposition								
Total operating	4.3	4.0	5.7	6.2	6.2	6.2	6.2	6.2
Technical personnel	15.8	16.0	21.4	23.0	23.0	23.0	23.0	23.0
Other direct personnel	0.6	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total direct personnel	16.4	16.8	22.2	23.8	23.8	23.8	23.8	23.8
Office of Civilian Radioactive Waste Management								
Nuclear Waste Fund—DB								
Total operating	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	2.3	0.5	0.3	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.3	0.5	0.3	0.0	0.0	0.0	0.0	0.0
Total Office of Civilian Radioactive Waste Management								
Total operating	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	2.3	0.5	0.3	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.3	0.5	0.3	0.0	0.0	0.0	0.0	0.0
Office of Nonproliferation and National Security								
Emergency Preparedness—NB								
Total operating	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	0.0	0.6	0.3	0.4	0.4	0.4	0.4	0.4
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.0	0.6	0.3	0.4	0.4	0.4	0.4	0.4
Total Office of Nonproliferation and National Security								
Total operating	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	0.0	0.6	0.3	0.4	0.4	0.4	0.4	0.4
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.0	0.6	0.3	0.4	0.4	0.4	0.4	0.4

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Office of Environment, Safety, and Health								
Environmental Research and Development—HA								
Total operating	10.3	9.3	12.7	11.1	11.1	11.1	11.1	11.1
Capital equipment	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Total program	10.3	9.3	12.7	11.2	11.2	11.2	11.2	11.2
Technical personnel	20.8	28.7	33.5	27.2	27.2	27.2	27.2	27.2
Other direct personnel	2.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2
Total direct personnel	23.2	29.0	33.7	27.4	27.4	27.4	27.4	27.4
Nuclear Safety Policy—HP								
Total operating	2.1	1.5	2.7	2.7	2.7	2.7	2.7	2.7
Technical personnel	6.7	7.7	8.2	8.8	8.8	8.8	8.8	8.8
Other direct personnel	1.1	2.4	2.6	2.0	2.0	2.0	2.0	2.0
Total direct personnel	7.8	10.1	10.8	10.8	10.8	10.8	10.8	10.8
Office of Nuclear Safety—NS								
Total operating	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Total Office of Environment, Safety, and Health								
Total operating	12.5	10.9	15.4	13.8	13.8	13.8	13.8	13.8
Capital equipment	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Total program	12.5	10.9	15.4	13.9	13.9	13.9	13.9	13.9
Technical personnel	27.6	36.6	41.7	36.0	36.0	36.0	36.0	36.0
Other direct personnel	3.5	2.7	2.8	2.2	2.2	2.2	2.2	2.2
Total direct personnel	31.1	39.3	44.5	38.2	38.2	38.2	38.2	38.2
Office of Human Resources and Administration								
Scientific and Engineering Recruitment, T&D—TR								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Office of Human Resources and Administration								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Policy, Planning and Program Evaluation								
International Affairs and Energy Emergencies—NA								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Emergency Planning—NC								
Total operating	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.7	0.3	0.2	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.7	0.3	0.2	0.0	0.0	0.0	0.0	0.0

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Policy, Analysis, and System Studies—PE								
Total operating	1.0	0.3	1.0	1.0	1.0	1.0	1.0	1.0
Technical personnel	4.5	5.3	4.4	4.4	4.4	4.4	4.4	4.4
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	4.6	5.3	4.4	4.4	4.4	4.4	4.4	4.4
Total Office of Policy, Planning and Program Evaluation								
Total operating	1.2	0.4	1.0	1.0	1.0	1.0	1.0	1.0
Technical personnel	5.3	5.6	4.6	4.4	4.4	4.4	4.4	4.4
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	5.4	5.6	4.6	4.4	4.4	4.4	4.4	4.4
Federal Energy Research Commission								
Federal Energy Regulatory Commission—VR								
Total operating	0.6	0.0	1.2	0.6	0.6	0.6	0.6	0.6
Technical personnel	5.0	10.0	5.9	4.2	4.2	4.2	4.2	4.2
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	5.0	10.0	5.9	4.2	4.2	4.2	4.2	4.2
Total Federal Energy Regulatory Commission								
Total operating	0.6	0.0	1.2	0.6	0.6	0.6	0.6	0.6
Technical personnel	5.0	10.0	5.9	4.2	4.2	4.2	4.2	4.2
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	5.0	10.0	5.9	4.2	4.2	4.2	4.2	4.2
Office of Economic Impact and Diversity								
Government Administration—Program Direction—WA								
Total operating	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Total Office of Economic Impact and Diversity								
Total operating	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0
DOE Funding from Lockheed Martin Energy Systems Central Organizations								
Environmental Restoration and Waste Management—Defense—EW								
Total operating	85.2	96.6	75.0	75.0	75.0	75.0	75.0	75.0
Capital equipment	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	22.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	110.5	96.6	75.0	75.0	75.0	75.0	75.0	75.0
Technical personnel	272.0	254.6	239.2	240.3	240.3	240.3	240.3	240.3
Other direct personnel	73.4	62.6	71.8	71.8	71.8	71.8	71.8	71.8
Total direct personnel	345.4	317.2	311.0	312.1	312.1	312.1	312.1	312.1

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Environmental Restoration and Waste Management—Non-Defense—EX								
Total operating	68.4	61.3	65.0	65.0	65.0	65.0	65.0	65.0
Capital equipment	0.1	(0.3)	0.0	0.0	0.0	0.0	0.0	0.0
Construction	22.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	90.9	61.0	65.0	65.0	65.0	65.0	65.0	65.0
Technical personnel	268.1	252.6	258.1	258.1	258.1	258.1	258.1	258.1
Other direct personnel	106.6	98.1	84.8	84.8	84.8	84.8	84.8	84.8
Total direct personnel	374.7	350.7	342.9	342.9	342.9	342.9	342.9	342.9
Total DOE Funding from Energy Systems Central Organizations								
Total operating	153.6	157.9	140.0	140.0	140.0	140.0	140.0	140.0
Capital equipment	2.6	(0.3)	0.0	0.0	0.0	0.0	0.0	0.0
Construction	45.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	201.4	157.6	140.0	140.0	140.0	140.0	140.0	140.0
Technical personnel	540.1	507.2	497.3	498.4	498.4	498.4	498.4	498.4
Other direct personnel	180.0	160.7	156.6	156.6	156.6	156.6	156.6	156.6
Total direct personnel	720.1	667.9	653.9	655.0	655.0	655.0	655.0	655.0
Subtotal—DOE Programs								
Operating expense	474.6	415.6	505.2	528.2	528.2	528.2	528.2	528.2
Capital equipment	23.3	32.4	37.9	35.2	35.2	35.2	35.2	35.2
Construction	79.5	16.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	12.4	35.2	33.9	3.4	1.2	0.0
Total program	577.4	464.2	555.5	598.6	597.3	566.8	564.6	563.4
Technical personnel	1532.6	1478.0	1486.7	1509.6	1509.6	1509.6	1509.6	1509.6
Other direct personnel	381.9	345.1	401.1	399.8	399.8	399.8	399.8	399.8
Total direct personnel	1914.5	1823.1	1887.8	1909.4	1909.4	1909.4	1909.4	1909.4
DOE Contractors and Operations Office								
Operating expense	18.3	14.4	7.3	7.1	7.1	7.1	7.1	7.1
Capital equipment	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	22.0	14.4	7.3	7.1	7.1	7.1	7.1	7.1
Technical personnel	59.9	49.1	31.1	23.9	24.4	24.4	24.4	24.4
Other direct personnel	12.3	4.6	1.1	0.5	0.0	0.0	0.0	0.0
Total direct personnel	72.2	53.7	32.2	24.4	24.4	24.4	24.4	24.4
Cooperative R&D Agreements								
Operating expense	0.7	1.1	0.6	0.3	0.3	0.3	0.3	0.3
Technical personnel	2.5	4.1	1.3	0.6	0.6	0.6	0.6	0.6
Other direct personnel	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.6	4.1	1.4	0.6	0.6	0.6	0.6	0.6
Total DOE Programs								
Operating expense	493.6	431.1	513.1	535.6	535.6	535.6	535.6	535.6
Capital equipment	27.0	32.4	37.9	35.2	35.2	35.2	35.2	35.2
Construction	79.5	16.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	12.4	35.2	33.9	3.4	1.2	0.0
Total	600.1	479.7	563.4	606.0	604.7	574.2	572.0	570.8
Technical personnel	1595.0	1531.2	1519.1	1534.1	1534.6	1534.6	1534.6	1534.6
Other direct personnel	394.3	349.7	402.2	400.3	399.8	399.8	399.8	399.8
Total direct personnel	1989.3	1880.9	1921.3	1934.4	1934.4	1934.4	1934.4	1934.4

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Work for others								
Nuclear Regulatory Commission								
Operating expense	16.3	13.3	13.8	13.4	13.4	13.4	13.4	13.4
Capital equipment	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	16.5	13.3	13.8	13.4	13.4	13.4	13.4	13.4
Technical personnel	82.3	75.3	67.9	68.5	68.5	68.5	68.5	68.5
Other direct personnel	4.4	2.5	2.1	1.5	1.5	1.5	1.5	1.5
Total direct personnel	86.7	77.8	70.0	70.0	70.0	70.0	70.0	70.0
Department of Defense								
Operating expense	25.6	14.5	20.9	21.9	21.9	21.9	21.9	21.9
Capital equipment	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	34.3	14.5	20.9	21.9	21.9	21.9	21.9	21.9
Technical personnel	117.9	98.3	95.7	88.3	88.3	88.3	88.3	88.3
Other direct personnel	10.5	0.6	0.3	0.2	0.2	0.2	0.2	0.2
Total direct personnel	128.4	98.9	96.0	88.5	88.5	88.5	88.5	88.5
National Aeronautics and Space Administration								
Operating expense	2.4	3.0	2.2	2.2	2.2	2.2	2.2	2.2
Technical personnel	7.6	9.4	8.2	7.0	7.0	7.0	7.0	7.0
Other direct personnel	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total direct personnel	8.2	9.7	8.5	7.3	7.3	7.3	7.3	7.3
Department of Health and Human Services								
Operating expense	3.2	3.0	4.5	4.5	4.5	4.5	4.5	4.5
Technical personnel	15.9	23.8	19.3	18.8	18.3	18.3	18.3	18.3
Other direct personnel	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel	16.0	23.9	19.4	18.4	18.4	18.4	18.4	18.4
Environmental Protection Agency								
Operating expense	1.7	0.9	1.4	1.4	1.4	1.4	1.4	1.4
Technical personnel	15.0	15.5	8.7	8.4	8.4	8.4	8.4	8.4
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	15.1	15.5	8.7	8.4	8.4	8.4	8.4	8.4
National Science Foundation								
Operating expense	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Federal Emergency Management Agency								
Operating expense	1.6	0.7	1.0	4.5	4.5	4.5	4.5	4.5
Capital equipment	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total program	1.6	0.8	1.1	4.6	4.6	4.6	4.6	4.6
Technical personnel	3.3	5.0	2.4	13.2	13.2	13.2	13.2	13.2
Other direct personnel	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	3.9	5.0	2.4	13.2	13.2	13.2	13.2	13.2

Table 8.5
(continued)

	1995	1996	1997	1998	1999	2000	2001	2002
Department of Transportation								
Operating expense	17.5	5.1	3.4	5.6	5.6	5.6	5.6	5.6
Capital equipment	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Total program	17.8	5.5	3.7	5.9	5.9	5.9	5.9	5.9
Technical personnel	25.0	43.0	28.6	21.6	21.6	21.6	21.6	21.6
Other direct personnel	1.1	2.0	2.0	1.0	1.0	1.0	1.0	1.0
Total direct personnel	26.1	45.0	30.6	22.6	22.6	22.6	22.6	22.6
Other Federal agencies								
Total operating	(4.7)	2.3	6.0	4.8	4.8	4.8	4.8	4.8
Technical personnel	13.5	22.7	22.8	19.9	19.9	19.9	19.9	19.9
Other direct personnel	0.9	2.1	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	14.4	24.8	22.8	19.9	19.9	19.9	19.9	19.9
Electric Power Research Institute								
Operating expense	1.4	1.8	0.9	0.4	0.4	0.4	0.4	0.4
Technical personnel	6.2	6.2	3.9	1.9	1.9	1.9	1.9	1.9
Other direct personnel	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel	6.4	6.3	4.0	2.0	2.0	2.0	2.0	2.0
Other nonfederal agencies								
Total operating	7.2	10.6	6.8	5.8	5.8	5.8	5.8	5.8
Capital equipment	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7.4	10.6	6.8	5.8	5.8	5.8	5.8	5.8
Technical personnel	21.4	38.7	22.1	14.0	14.0	14.0	14.0	14.0
Other direct personnel	2.4	1.4	3.8	1.0	1.0	1.0	1.0	1.0
Total direct personnel	23.8	40.1	25.9	15.0	15.0	15.0	15.0	15.0
Total Work for Others								
Total operating	72.2	55.3	60.9	64.5	64.5	64.5	64.5	64.5
Capital equipment	9.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4
Total	81.6	55.8	61.3	64.9	64.9	64.9	64.9	64.9
Technical personnel	308.5	337.9	279.6	261.1	261.1	261.1	261.1	261.1
Other direct personnel	20.9	9.1	8.7	4.2	4.2	4.2	4.2	4.2
Total direct personnel	329.4	347.0	288.3	265.3	265.3	265.3	265.3	265.3
Total Program Resources								
Operating expense	565.8	486.4	574.0	600.1	600.1	600.1	600.1	600.1
Capital equipment	36.4	32.9	38.3	35.6	35.6	35.6	35.6	35.6
Construction	79.5	16.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	12.4	35.2	33.9	3.4	1.2	0.0
Total	681.7	535.5	624.7	670.9	669.6	639.1	636.9	635.7
Technical personnel	1903.5	1869.1	1798.7	1795.2	1795.7	1795.7	1795.7	1795.7
Other direct personnel	415.2	358.8	410.9	404.5	404.0	404.0	404.0	404.0
Total direct personnel	2318.7	2227.9	2209.6	2199.7	2199.7	2199.7	2199.7	2199.7

Table 8.6
Estimated subcontracting and procurement by fiscal year
($ in millions—obligated)

	1995[a]	1996	1997	1998
Universities	26.9	27.9	28.8	29.7
All others	185.3	191.7	198.5	195.1
Transfers to other DOE facilities	5.2	5.1	5.5	5.6
Total external subcontracts and procurements	217.4	224.7	232.8	230.4

[a]Actual.

Table 8.7
Estimated small and disadvantaged business procurement by fiscal year
($ in millions—BA)

	1995	1996
Total small and disadvantaged business	91.9	94.6
Disadvantaged business	22.3	22.8
Women- and minority-owned business	15.6	16.1
Labor surplus (economically depressed area)	27.2	27.9

Appendix A • Statistical Information

Guest and User Facility Data

Statistics on the number of guests at ORNL are collected by the Office of Science and Technology Partnerships (Partnership Office). Data for the last three years are presented in Table A.1.

The Partnership Office also collects information on the use of ORNL's designated user facilities. Data for FY 1995 are presented in Table A.2.

Science and Mathematics Education Data

Statistics on the number of students participating in ORNL education programs are collected by the Office of University and Science Education. Data for the last two years for which complete information is available are presented in Table A.3.

Table A.1
Guests at ORNL by fiscal year

	1993	1994	1995
Federal agency	70	75	69
Foreign institution	81	84	74
High school faculty and students	135	167	100
Leased personnel	361	344	386
University			
Faculty	415	466	478
Postdoctoral	199	242	243
Graduate student	319	334	495
General	858	1016	944
Self-employed consultant	281	340	371
Industry	862	985	1217
Total	3581	4053	4377

Table A.2
Experimenters at ORNL's designated user research facilities in FY 1995[a]

	U.S. government laboratory[b]			University			Industry			International			Total		
	Exp.[c]	Org.[d]	% of use	Exp.	Org.	% of use	Exp.	Org.	% of use	Exp.	Org.	% of use	Exp.	Org.	User days
Computational Center for Industrial Innovation	25	1	21	30	2	48	4	2	31	0	0	0	59	5	112
National Environmental Research Park[e]	48	5	44	62	20	24	39	5	32	0	0	0	149	30	4,054
High Temperature Materials Laboratory	154	6	83	94	40	4	63	35	13	0	0	0	311	81	46,481
Surface Modification and Characterization Research Center	37	5	56	60	21	38	9	4	5	7	6	2	113	36	2,518
Shared Research Equipment Program	32	1	62	33	18	29	1	1	<1	4	4	9	70	24	2,052
High Flux Isotope Reactor[f]	42	7	45	68	27	34	8	7	3	33	20	18	151	61	1,826
EN Tandem Van de Graaff	11	1	44	18	1	54	0	0	0	2	2	2	31	4	1,724
Oak Ridge Electron Linear Accelerator[g]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bioprocessing Research and Development Center	11	1	72	2	2	22	3	2	6	0	0	0	16	5	235
Buildings Technology Center	2	1	27	5	4	28	17	16	12	3	2	33	27	23	546
Oak Ridge Centers for Manufacturing Technology	28	1	33	47	8	48	20	5	19	0	0	0	95	14	978
Total	390	29	75	419	143	11	164	77	13	49	34	1	1,022	283	60,526

[a]The Holifield Radioactive Ion Beam Facility did not operate as a user facility during FY 1995. User operation will be resumed in FY 1997.

[a]Includes 347 ORNL users (34% of use).

[b]Exp. = number of experimenters.

[c]Org. = number of organizations.

[e]Numbers do not include over 25,000 individuals who participated in the Ecological and Physical Sciences Study Center and the High School Honors Program for a total of 10,434 user hours in FY 1995.

[f]Formerly the Neutron Scattering Research Facilities.

[g]No user statistics were collected at this facility in FY 1995.

Table A.3
Participation in science and math education programs

	FY 1994			FY 1995		
	Total	Minorities	Women	Total	Minorities	Women
Precollege student programs						
Adventures in Math/Science	100	54	47	45	9	24
Adventures in Supercomputing	528	45	241	482	118	212
ARC Honors Academy	33	2	18	39	2	19
DOE Honors Workshop	57	11	38	—	—	—
Clinch River Environmental Studies Organization	22	1	13	23	1	13
Oak Ridge Educational Network	800	*a*	*a*	900	*a*	*a*
Project SEED/Hispanic SEED	15	10	10	17	8	11
Regional Science Bowls	270	30	65	125	15	55
Saturday Academy of Computing and Mathematics	28	2	13	48	5	20
Special Honors Study	2	0	1	3	0	1
Spectacles Camp, Wesleyan College	22	3	22	72	7	72
Ecological and Physical Sciences Study Center	23,734	2,100	11,800	22,303	1,800	11,150
Summer Science Experience	46	4	20	47	4	25
Women in Science and Technology Conference	100	12	100	100	12	100
Junior Science/Humanities	129	10	66	85	7	46
Special presentations	450	102	220	1,064	160	500
Total	26,336	2,386	12,674	25,353	2,148	12,248
Precollege teacher programs						
Academy for Teachers of Science and Mathematics	80	7	53	79	8	50
Academy Alumni	*a*	*a*	*a*	133	15	93
Administrators Workshop	30	2	17	43	4	20
Adventures in Supercomputing	37	3	25	43	3	27
ARC Honors Academy	14	0	6	9	0	3
ARC Teacher Leadership Institute	—	—	—	9	0	3
DOE Honors Workshop	4	1	2	—	—	—
DOE Teacher Research Associates	42	8	20	34	5	20
DOE Lyndhurst Fellows	12	0	4	12	0	3
Elementary Leadership Institute (NSF)	24	4	22	22	4	21
Hands-On Science Workshops	22	2	18	10	0	8
Manufacturing Opportunities through Science and Technology (MOST)	*a*	*a*	*a*	25	3	10
Project SMART	90	2	73	—	—	—
Science Enrichment	10	2	7	10	2	7
Saturday Academy of Computing and Mathematics	6	0	4	19	2	8
Teacher In-Service Training	354	40	221	1,079	120	650
Total	725	71	472	1,527	166	923

Table A.3
(continued)

	FY 1994			FY 1995		
	Total	Minorities	Women	Total	Minorities	Women
Undergraduate programs						
Alliance for Minority Participation	6	4	6	4	4	2
Buildings Technology Internships	3	3	2	2	2	1
Cooperative Education Internships	67	22	23	58	14	21
Customized Internships (HBCU)	2	2	2	4	4	2
DOE Science and Engineering Research Semester	77	11	29	62	12	24
Environmental Management Career Opportunities for Minorities (EMCOM)	22	22	15	—	—	—
Graduate School Fair	325	60	180	290	50	155
Great Lakes Colleges Association/ Associated Colleges of the Midwest Science Semester	25	8	7	29	10	6
HBCU						
Health/Environment	5	5	1	1	1	1
Nuclear Energy	6	6	3	3	3	2
Nuclear Regulatory	12	12	2	9	9	2
Minority Challenge	*a*	*a*	*a*	1	1	1
NAACP Scholar	*a*	*a*	*a*	1	1	1
Professional Internship Program	72	11	28	100	19	39
Science and Engineering Research Semester, Summer Program	35	5	13	24	3	13
Science and Technology Alliance	13	12	5	25	25	11
Student Research Participation Program	25	2	9	29	2	8
Summer Technical Internship	44	8	19	58	15	29
Technology Internship Program	42	3	19	28	1	14
University of Puerto Rico	2	2	0	2	2	2
Women in Science Conference	200	25	198	180	25	178
Total	983	223	561	910	203	512
Graduate programs						
Advanced Industrial Concepts Materials Fellowship Program	2	2	0	2	2	0
DOE Fellowship Practicums	5	0	1	2	2	0
Graduate Student Research Participation Program	36	3	7	26	1	3
High Temperature Materials Laboratory Fellowships	4	0	0	6	0	3
Laboratory Graduate Research	9	0	1	5	0	1
Law Internship Program	7	1	3	3	0	0
National Consortium for Graduate Degrees for Minorities (GEMS)	3	3	1	3	3	2
Professional Internship Programs	48	4	15	52	5	21
Research Travel Contracts	10	0	5	35	0	4
University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences	*a*	*a*	*a*	20	11	0
Total	124	13	33	154	24	34

Table A.3
(continued)

	FY 1994			FY 1995		
	Total	Minorities	Women	Total	Minorities	Women
Postgraduate programs						
DOE Postdoctoral Programs						
Distinguished Postdoctoral	2	0	0	3	0	0
Fusion Energy	1	0	0	1	0	0
Global Change	4	0	0	3	0	0
Hollaender	6	0	2	6	0	3
Human Genome	2	0	0	1	0	0
ORNL Postdoctoral Research	193	5	31	198	7	27
Postgraduate Research Training Program	37	2	14	45	1	14
University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences	*a*	*a*	*a*	12	0	5
Wigner Postdoctoral Fellows	5	1	1	6	1	1
Total	250	8	48	275	9	50
Faculty programs						
Environmental Management Career Opportunities for Minorities (EMCOM)	1	1	0	0	0	0
Faculty Research Participation	40	9	12	51	11	5
Great Lakes Colleges Association/ Associated Colleges of the Midwest	3	0	1	3	0	1
HBCU Faculty Research	14	14	2	24	24	4
High Temperature Materials Laboratory Fellowships	*a*	*z*	*z*	4	1	1
Minority Institution Research Travel	8	8	1	—	—	—
Research Travel Contract Visits	36	8	2	117	61	6
Science and Technology Alliance	7	3	2	10	7	3
Total	109	43	20	209	104	20

[a]Not determined.

Human Resources Data

Statistics on the number of minority employees at ORNL are collected by the Human Resources organization. Data for 1990 and 1995 are presented in Tables A.4 and A.5.

Table A.4
Equal employment opportunity statistics for 1990

Occupational code	Total (%)[a]		Minority total (%)		White (%)		Black (%)		Hispanic (%)		Native American (%)		Asian/Pacific Islander (%)	
	M[b]	F[c]	M	F	M	F	M	F	M	F	M	F	M	F
Officials and managers[d]	533 (90.8)	54 (9.2)	27 (4.6)	3 (0.5)	506 (86.2)	51 (8.7)	23 (3.9)	2 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	4 (0.7)	1 (0.2)
Professional staff[e]														
Scientists	538 (83.0)	110 (17.0)	47 (7.3)	11 (1.7)	491 (75.8)	99 (15.3)	10 (1.5)	4 (8.6)	6 (0.9)	1 (0.1)	1 (0.1)	1 (0.1)	30 (4.6)	5 (0.7)
Engineers	1000 (90.9)	100 (9.1)	68 (6.2)	9 (0.8)	932 (84.7)	91 (8.3)	23 (2.0)	9 (0.8)	9 (0.8)	0 (0.0)	1 (0.09)	0 (0.0)	35 (3.2)	0 (0.0)
Administrative	327 (56.7)	250 (43.3)	24 (4.2)	24 (4.2)	303 (52.5)	226 (39.1)	13 (2.3)	14 (2.4)	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	10 (1.7)	10 (1.7)
Technicians	430 (68.6)	197 (31.4)	42 (6.7)	21 (3.3)	388 (61.8)	176 (28.0)	34 (5.4)	18 (2.9)	7 (1.1)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.1)	3 (0.4)
Clerical	42 (4.9)	809 (95.1)	10 (1.2)	100 (11.6)	32 (3.8)	709 (83.3)	9 (1.0)	90 (10.6)	0 (0.0)	6 (0.7)	1 (0.1)	0 (0.0)	0 (0.0)	4 (0.5)
Crafts/ laborers	721 (92.9)	55 (7.1)	91 (11.7)	12 (1.5)	630 (81.2)	43 (5.5)	86 (11.0)	12 (1.5)	2 (0.2)	0 (0.0)	1 (0.1)	0 (0.0)	2 (0.2)	0 (0.0)
Service workers	115 (71.9)	45 (28.1)	26 (16.2)	15 (9.4)	89 (55.6)	30 (18.7)	26 (16.2)	12 (7.5)	0 (0.0)	0 (0.0)	0 (0.0)	2 (1.3)	0 (0.0)	1 (0.6)
Total[f]	3706 (69.6)	1620 (30.4)	335 (6.3)	195 (3.7)	3371 (63.3)	1425 (26.8)	224 (4.2)	161 (3.0)	25 (0.5)	7 (0.1)	4 (0.07)	3 (0.05)	82 (1.5)	24 (0.4)

[a]Percentage of total number of employees in occupational category.
[b]M = male.
[c]F = female.
[d]As defined on Standard Form 100 (EEO-1), as required by 41 CFR 60-1.7(a).
[e]Management included in "Officials and managers" category.
[f]Total includes employees of multiple-site organizations.

Table A.5

Equal employment opportunity statistics for 1995

Occupational code	Total (%)[a]		Minority total (%)		White (%)		Black (%)		Hispanic (%)		Native American (%)		Asian/Pacific Islander (%)	
	M[b]	F[c]	M	F	M	F	M	F	M	F	M	F	M	F
Officials and managers[d]	359 (91.5)	33 (8.5)	26 (6.6)	2 (0.5)	333 (84.9)	31 (7.9)	22 (5.6)	2 (0.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	4 (1.0)	0 (0.0)
Professional staff[e]														
Scientists	493 (80.9)	116 (19.1)	56 (9.2)	18 (3.0)	437 (71.8)	98 (16.0)	11 (1.8)	7 (1.1)	7 (1.1)	2 (0.3)	1 (0.16)	1 (0.16)	37 (6.1)	8 (1.3)
Engineers	818 (89.9)	92 (10.1)	82 (9.0)	8 (0.8)	736 (80.9)	84 (9.2)	21 (2.3)	5 (0.5)	13 (1.4)	0 (0.0)	0 (0.0)	0 (0.0)	48 (5.3)	3 (0.3)
Administrative	348 (58.2)	249 (41.8)	33 (5.5)	29 (4.9)	315 (52.1)	220 (36.9)	18 (3.0)	18 (3.0)	7 (1.2)	3 (0.5)	0 (0.0)	0 (0.0)	8 (1.3)	8 (1.3)
Technicians	316 (70.0)	135 (30.0)	22 (4.9)	16 (3.5)	294 (65.2)	119 (22.0)	18 (4.0)	13 (2.9)	4 (0.8)	0 (0.0)	0 (0.0)	1 (0.2)	0 (0.0)	2 (0.4)
Clerical	11 (1.8)	594 (98.2)	1 (0.2)	69 (11.4)	10 (1.7)	525 (86.8)	1 (0.1)	60 (9.9)	0 (0.0)	5 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)	4 (0.7)
Crafts/ laborers	699 (92.2)	59 (7.8)	59 (7.8)	15 (2.0)	640 (91.5)	44 (6.3)	55 (7.9)	14 (1.8)	0 (0.0)	0 (0.0)	1 (0.1)	1 (0.1)	3 (0.4)	0 (0.0)
Service workers	38 (61.2)	24 (38.8)	11 (17.7)	11 (17.7)	27 (43.5)	13 (20.9)	11 (17.7)	9 (14.5)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.6)	0 (0.0)	1 (1.6)
Total	3082 (70.3)	1302 (29.7)	290 (6.6)	168 (3.8)	2792 (63.7)	1134 (25.9)	157 (3.6)	128 (2.9)	31 (0.7)	10 (0.2)	2 (0.04)	4 (0.09)	100 (2.9)	26 (0.6)

[a]Percentage of total number of employees in occupational category.
[b]M = male.
[c]F = female.
[d]As defined on Standard Form 100 (EEO-1), as required by 41 CFR 60-1.7(a).
[e]Management included in "Officials and managers" category.

Appendix B • Summaries of Other Plans

Integrated Facilities Plan

The Integrated Facilities Plan (IFP) defines ORNL's plans for facilities and site development. It also serves as a reference source for a broad base of site and facilities characterization data. Structured around a site development planning analysis, the IFP summarizes ORNL's present missions, programs, and population; reviews regional conditions; and describes site assets (land, buildings and other structures, utility distribution systems, transportation infrastructure, security and safety systems, and waste management systems).

An inventory of existing assets is provided. The construction projects required to support ORNL's future mission and program plans are described, and the impacts of these projects on the site's assets are summarized. Key elements of the site planning analysis are presented: assumptions and objectives for site development, an evaluation of the site for each objective, and alternatives for removing each site's deficiencies or excesses. A Master Plan for the site, with a 20- to 30-year time frame for full implementation, is developed and described. A review of the anticipated status of the site in ten years is presented to illustrate how the Master Plan is to be implemented.

ORNL Strategic Plan for Computing

ORNL's overall vision in computing is to become a premier center for computational science, where computational scientists desire to work, and where outreach to industry and education are central themes. Access to and manipulation of information on the desktop will become so easy that the computer will become the primary office tool for all ORNL staff.

To realize this vision, several long-term strategies have been identified. These strategies are organized into five areas: collaborations, computational sciences, high-performance computing and communications (HPCC) technologies, services, and user platforms.

Collaborations

Industry: ORNL will be a major partner with industry in projects that effectively transfer computing-related technologies to the private sector.

Education: While continuing its traditional strong involvement with undergraduate, graduate, and postgraduate education, ORNL will address lifelong learning through a focus on programs in education for students in kindergarten through high school.

Computational Sciences

In order to become a premier center for computational science, ORNL will focus on a few computational areas where it can build on existing strengths. The problems to be addressed will, in the main, be Grand Challenges, and emphasis will be placed on collaborative projects with, and in support of, industrial partners.

HPCC Technologies

ORNL will provide state-of-the-art HPCC support technologies to create a research ambiance to support the achievements of Grand Challenge computational science groups.

Computer hardware: ORNL will maintain its current leading position in obtaining high-performance research systems, developing systems, and production systems.

Data storage: ORNL will build on both current and planned storage experiments and systems to remain at the forefront of storage technology. ORNL will collaborate with industry and with other DOE laboratories in the use of these resources and this expertise.

Network research: ORNL will always have at least three technologies in the development queue: a research-level technology, a near-commercial technology, and a production-quality technology.

National Information Infrastructure: ORNL will be a leader in the deployment of information infrastructure technology in the manipulation of large datasets, in collaboration with research partners, and in its daily research environment.

Algorithms: ORNL will be at the forefront in the development and analysis of numerical algorithms for solving large-scale scientific and engineering problems on advanced computer architectures. Emphasis will be on the transfer of this algorithmic technology to applications such as high-level interfaces and/or integration into software libraries.

Informatics: ORNL informatics research and development will expand significantly beyond the initial and continuing focus on genome informatics to address fundamental and applied problems in intelligent information processing.

Software tools: ORNL will continue to build on its world-wide reputation for developing quality software tools such as Parallel Virtual Machine (PVM), while expanding the scope of generically useful tools being developed, such as those for using large datasets.

Visualization: ORNL will stay at the cutting edge of this fast moving field, both in the development of emerging visualization technologies and in their application across computational disciplines. This will necessitate more attention to this field than has been given in the past.

Services

Information resource management: ORNL will have a coordinated program in which all ORNL staff have access to the information they need, when they need it, without concern for the source or the logistics of the information flow.

Production systems: Corporate administrative and operational information will be provided to users on their desktops in a user-friendly, client/server form based on open systems standards. Production UNIX environments will be available for scientific and technical computing users who do not have the necessary resources within their divisions.

Production networks: ORNL intends to continue to provide a high-speed fiber-optic backbone and connections to the Internet. Bridges, routers, network monitoring, and name service are provided. Services are provided to allow users to easily connect to this infrastructure via Ethernet or better.

Information servers: ORNL staff will have desktop computer access to management, compliance, scientific, engineering, and marketing information in immediately accessible, searchable, standard electronic form. Information server software to be used by a large population of clients should be designed with input from the user population. Seamless systems should be in place to allow for all ORNL employees to publish and provide electronic information that is accessible to computer users internal and external to Lockheed Martin Energy Systems, Inc.

User Platforms

ORNL will modernize its desktop computing and networking hardware and software to reduce overall cost and to facilitate information access and exchange.

Appendix C • Related Documents

- *Biological and Environmental Research Program at Oak Ridge National Laboratory,* ORNL/M-5001, Lockheed Martin Energy Research, 1996
- *Energy Systems Programs Funded by the Assistant Secretary for Environment, Safety, and Health, FY 1995,* ORNL/M-4849, Lockheed Martin Energy Research, 1995
- *Environmental Data Management Implementation Handbook for the Environmental Restoration Program,* ES/ER/TM-88/R1, Lockheed Martin Energy Systems, Inc.
- *Lockheed Martin Energy Research Corporation ES&H Management Plan for the Oak Ridge National Laboratory,* Lockheed Martin Energy Research, March 1996
- *Oak Ridge National Laboratory R&D Strategic Plan, May 1995,* available from the Office of Planning and Special Projects, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee 37831-6251
- *ORNL Integrated Facilities Plan,* ORNL/PPA-94/2, Martin Marietta Energy Systems, Inc., April 1994. Also available on CD-ROM.
- *Strategic Plan for Computing at Oak Ridge National Laboratory,* ORNL/PPA/INT-94/2, Martin Marietta Energy Systems, September 1994
- J. B. Roberto et al., *Oak Ridge National Laboratory: Core Competencies,* ORNL/PPA-94/4, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, December 1994
- *Strategic Laboratory Missions Plan—Phase 1,* available from the Office of Public Affairs, CP-41, U.S. Department of Energy, 1000 Independence Avenue SW, Washington, DC 20585, or at <http://www.doe.gov/html/doe/whatsnew/labmsspl/summary.html> on the World Wide Web

Appendix D • Abbreviations

AA	affirmative action
AART	Alliance for the Advancement of Robotics Technology
ADS	activity data sheet
AEOD	NRC Office for Analysis and Evaluation of Operational Data
AEP	Division of Advanced Energy Projects
AHAM	Association of Home Appliance Manufacturers
AID	U.S. Agency for International Development
AIDS	acquired immunodeficiency syndrome
AMCL	Advanced Materials Characterization Laboratory
AMS	Applied Mathematical Sciences
AMTEX	American Textile Partnership
ANL	Argonne National Laboratory
appm	atomic parts per million
ARM	Atmospheric Radiation Measurement
ASDEX-U	Axially Symmetric Divertor Experiment Upgrade
ASP	Accident Sequence Precursor
ATS	Advanced Turbine System
AZT	azidothymidine
B&W	Babcock and Wilcox
BA	budget authority
BES	Basic Energy Sciences
BESAC	Basic Energy Sciences Advisory Committee
BFDP	Biofuels Feedstock Development Program
BNL	Brookhaven National Laboratory
BO	budget outlay
BRDC	Bioprocessing Research and Development Center
BTC	Buildings Technology Center
BTS	Office of Building Technology, State and Community Programs
BWR	boiling-water reactor
C-CAP	Coastal Change Analysis Program
CADDET	Center for Analysis and Dissemination of Demonstrated Energy Technologies
CAMP	Capital Asset Management Process
CANDU	Canadian deuterium-uranium reactor
CCII	Computational Center for Industrial Innovation
CCS	Center for Computational Sciences
CCTP	Clean Coal Technology Program
CDIAC	Carbon Dioxide Information Analysis Center
cDNA	complementary deoxyribonucleic acid
CERN	European Laboratory for Particle Physics (formerly Conseil Européen pour la Recherche Nucléaire)
CESAR	Center for Engineering Systems Advanced Research
CESP	Center of Excellence for Synthesis and Processing
CFADC	Controlled Fusion Atomic Data Center

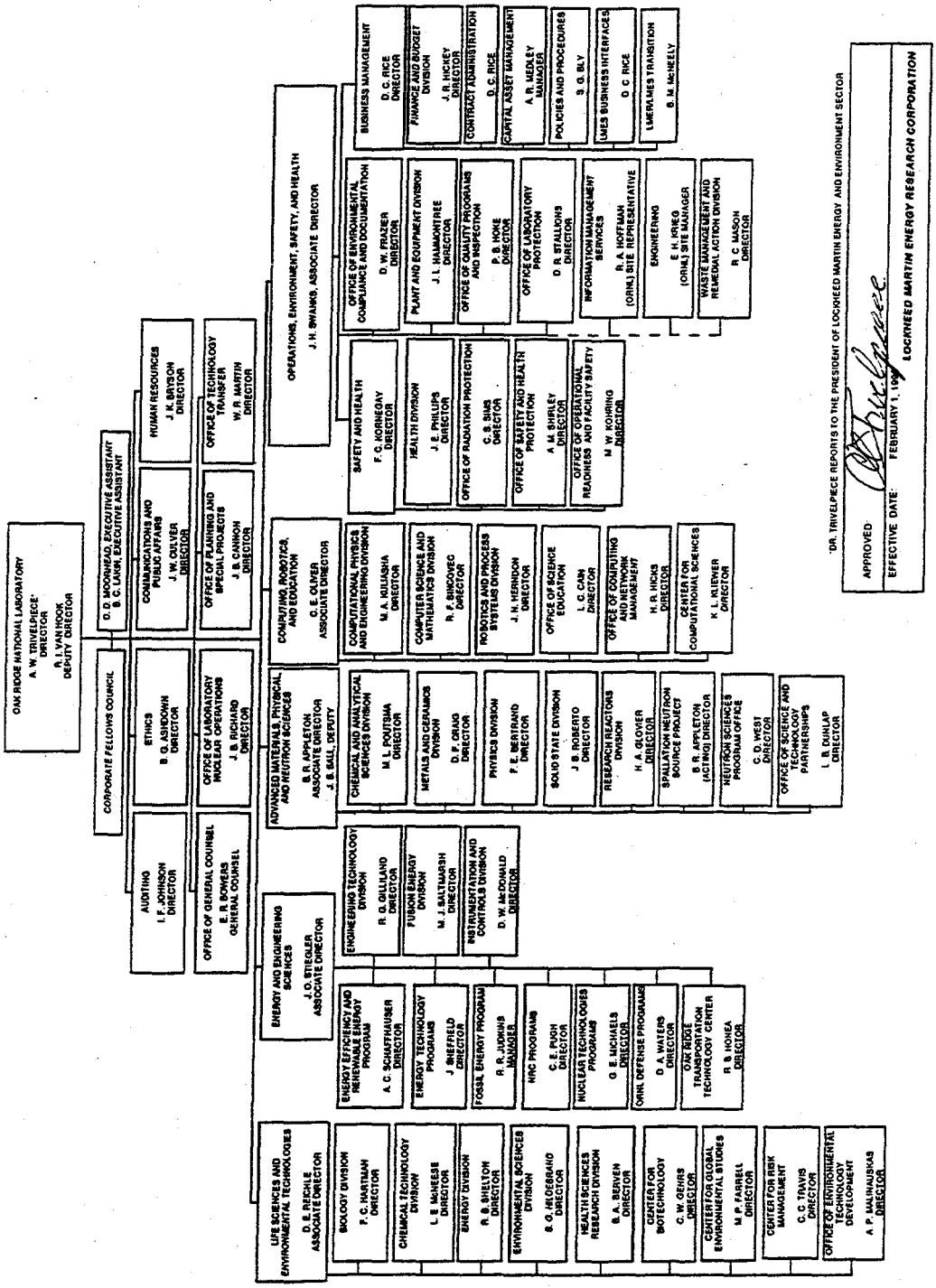
CFC	chlorofluorocarbon
CFCC	continuous fiber ceramic composite
CFR	Code of Federal Regulations
CGES	Center for Global Environmental Studies
CGH	computer-generated hologram
CHAMMP	Computer Hardware, Advanced Mathematics, and Model Physics
CHS	Compact Helical System
CRADA	cooperative research and development agreement
CSCP	Center for Separations and Chemical Processing
CTA	Center for Transportation Analysis
CURE	Chemical Unit Record Estimates
D&D	decontamination and decommissioning
D-T	deuterium-tritium
DAAC	Distributed Active Archive Center
DAE	differential-algebraic equation
DNA	deoxyribonucleic acid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE-DP	U.S. Department of Energy, Office of Defense Programs
DOE-EE	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
DOE-EH	U.S. Department of Energy, Office of Environment, Safety, and Health
DOE-EM	U.S. Department of Energy, Office of Environmental Management
DOE-ER	U.S. Department of Energy, Office of Energy Research
DOE-FE	U.S. Department of Energy, Office of Fossil Energy
DOE-HQ	U.S. Department of Energy, Headquarters
DOE-NE	U.S. Department of Energy, Office of Nuclear Energy, Science and Technology
DOE-ORO	U.S. Department of Energy, Oak Ridge Operations Office
DOT	U.S. Department of Transportation
DRS	Daresbury Recoil Separator
DSM	demand-side management
ECR	electron cyclotron resonance
EEO	equal employment opportunity
EEO/AA	equal employment opportunity/affirmative action
EES	Evaluation of Early Systems
EIA	Energy Information Administration
EMF	electric and magnetic fields
EMIC	Environmental Mutagen Information Center
EMSP	Environmental Management Science Program
EOSDIS	Earth Observing System Data and Information System
EPA	U.S. Environmental Protection Agency
EPACT	Environmental Policy Act of 1992
EPIC	Employees Participating in Change
EPRI	Electric Power Research Institute
ER-LTR	Energy Research Laboratory Technology Research Program
ERIP	Energy-Related Inventions Program
ES&H	environment, safety, and health
ESH&Q	environment, safety, health, and quality
ESHQC	Environment, Safety, Health, and Quality Committee
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FFA	Federal Facilities Agreement
FHWA	Federal Highway Administration
FTE	full-time equivalent

FTMS	Fourier transform masss spectrometry
FUSRAP	Formerly Utilized Sites Remedial Action Project
FY	fiscal year
GAX	generator–absorber–heat exchanger
GCM	general circulation model
GEMS	National Consortium for Graduate Degrees for Minorities in Science and Engineering, Inc.
GMODS	glass material oxidation and dissolution system
GO-NII	Gas and Oil National Information Infrastructure
GPE	general-purpose equipment
GPP	general plant project
GRAIL	Gene Recognition and Analysis Internet Link
GREENTIE	Greenhouse Gas Technology Information Exchange
GSF	gross square feet
HBCU	historically black college or university
HCFC	hydrochlorofluorocarbon
HEU	highly enriched uranium
HFIR	High Flux Isotope Reactor
HGMIS	Human Genome Management Information System
HIV	human immunodeficiency virus
HPCC	High Performance Computing and Communications
HPSS	High Performance Storage System
HRIBF	Holifield Radioactive Ion Beam Facility
HSSI	NRC Heavy-Section Steel Irradiation Program
HSST	NRC Heavy-Section Steel Technology Program
HTML	High Temperature Materials Laboratory
I&C	instrumentation and controls
IAEA	International Atomic Energy Agency
ICRF	ion cyclotron range of frequencies
IEA	International Energy Agency
IEF	Isotope Enrichment Facility
IFP	Integrated Facilities Plan
IMP	Infrastructure Management Plan
IMSL	Intelligent Measurement Systems Laboratory
INEL	Idaho National Engineering Laboratory
IOF	Industries of the Future
IRM	information resource management
ISOL	isotope separator on-line
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
LANL	Los Alamos National Laboratory
LBNL	Ernest Orlando Lawrence Berkeley National Laboratory
LDRD	Laboratory Directed Research and Development
linac	linear accelerator
LLLW	low-level liquid waste
LLNL	Lawrence Livermore National Laboratory
LMER	Lockheed Martin Energy Research Corporation
LMES	Lockheed Martin Energy Systems, Inc.
LOF	liquid-overfeed
LWR	light-water reactor
MAb	monoclonal antibody
MALDI	matrix-assisted laser desorption/ionization
MEI	minority educational institution
MEL-FS	Multiprogram Energy Laboratories Facilities Support

MOX	mixed-oxide
MPLUS	Metals Processing Laboratory User Center
MPP	massively parallel processing
N&S	necessary and sufficient
NASA	National Aeronautics and Space Administration
NCI	National Cancer Institute
NEAT	National Energy Audit
NEPA	National Environmental Policy Act
NICHHD	National Institute for Child Health and Human Development
NIEHS	National Institute for Environmental Health Sciences
NIH	National Institutes of Health
NII	National Information Infrastructure
NMR	nuclear magnetic resonance
NMSS	NRC Office of Nuclear Material Safety and Safeguards
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NSF	National Science Foundation
NSNS	National Spallation Neutron Source
NSTX	National Spherical Tokamak Experiment
OEPA	DOE Office of Environmental Policy and Assistance
OES&H	Operations, Environment, Safety, and Health
OFES	DOE Office of Fusion Energy Sciences
OHER	DOE Office of Health and Environmental Research
OIT	Office of Industrial Technologies
ORCMT	Oak Ridge Centers for Manufacturing Technology
ORELA	Oak Ridge Electron Linear Accelerator
ORISE	Oak Ridge Institute for Science and Education
ORNL	Oak Ridge National Laboratory
ORSOAR	ORNL-ORISE Synchrotron Organization for Advanced Research
ORTRAN	Oak Ridge Transportation Technology Center
OSH	occupational safety and health
OSTI	Office of Scientific and Technical Information
OUSE	Office of University and Science Education
P2	pollution prevention
PC/ESCO	performance contracting and energy service companies
PEBB	Power Electronics Building Block
PER	Program for Ecosystem Research
PHENIX	Pioneering High-Energy Nuclear Interaction Experiment
PNGV	Partnership for a New Generation of Vehicles
PPPL	Princeton Plasma Physics Laboratory
PVM	Parallel Virtual Machine
QA	quality assurance
R&D	research and development
RAP	remedial action project
RCRA	Resource Conservation and Recovery Act
RDDT&E	research, development, demonstration, testing, and evaluation
REDC	Radiochemical Engineering Development Center
RELAP	Reactor Loss of Coolant Analysis Program
RES	NRC Office of Nuclear Regulatory Research
rf	radio frequency
RHIC	Relativistic Heavy Ion Collider
RIB	radioactive ion beam
RMS	recoil mass spectrometer
RNA	ribonucleic acid

RPV	reactor pressure vessel
RRD	Research Reactors Division
RSIC	Radiation Shielding Information Center
RTG	radioisotope thermoelectric generator
S&M	surveillance and maintenance
S/RID	Standards/Requirements Identification Document
SCALE	Standardized Computer Analysis for Licensing Evaluation
SCDAP	Severe Core Damage Analysis Program
SCSS	Sequence Coding and Search System
SECME	Southeastern Consortium for Minorities in Engineering
SEED	Summer Educational Experience for the Disadvantaged
SERDP	Strategic Environmental Research and Development Program
SERS	surface-enhanced Raman spectroscopy
SFMP	Surplus Facilities Management Program
SHaRE	Shared Research Equipment
SIAC	specialized information analysis center
SMACRC	Surface Modification and Characterization Research Center
SMART	Science/Math Action for Revitalized Teaching
SNL	Sandia National Laboratories
SSP	Subsurface Science Program
ST	Spherical Tokamak
TEXTOR	Tokamak Experiment for Technology Oriented Research
TFTR	Tokamak Fusion Test Reactor
TIRC	Toxicology Information Response Center
TSU	Tennessee State University
TTI	Technology Transfer Initiative
TVA	Tennessee Valley Authority
UMTRAP	Uranium Mill Tailings Remedial Action Project
UNI-CAT	University–National Laboratory–Industry Collaborative Access Team
USDA	U.S. Department of Agriculture
UT	The University of Tennessee
UV-B	ultraviolet B
VP	virtual prototyping
W7-AS	Wendelstein 7-AS
WDC-A	World Data Center–A for Atmospheric Trace Gases
WMRAD	Waste Management and Remedial Action Division
WWW	World Wide Web
YBCO	yttrium–barium–copper oxide

Laboratory Organization Chart



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