ORNL/PPA-2000/2

Oak Ridge National Laboratory

Institutional Plan

FY 2001–FY 2005

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ORNL/PPA-2000/2

Oak Ridge National Laboratory Institutional Plan

FY 2001–FY 2005

November 2000

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6285
managed by
UT-Battelle LLC
for the
U.S. Department of Energy
under contract DE-AC05-00OR22725

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Contents

1 • Laboratory Director's Statement

On April 1, 2000, UT-Battelle LLC, a partnership between the University of Tennessee (UT) and Battelle, assumed the management and operation of the Oak Ridge National Laboratory (ORNL) for the U.S. Department of Energy (DOE). This first Institutional Plan prepared by the new contractor captures the philosophy, goals, strategies, initiatives, and major themes that will shape the future direction of this great national asset.

UT and Battelle formed this new partnership because the two organizations share a common vision for ORNL's future. The vision is based on each partner's commitment, spanning more than 50 years, to DOE, its missions, and especially its laboratories. At the core of this plan is a philosophical commitment to excellence in science and technology; Laboratory operations and environment, safety, and health (ES&H); and community service. This balanced management approach reflects our commitment to "Simultaneous Excellence." The UT-Battelle Leadership Team will deliver on this commitment through a comprehensive Laboratory Agenda that delineates ORNL's strategic objectives (which have a time horizon of 5 to 10 years), critical outcomes (3 to 5 years), Laboratory-level initiatives (1 to 3 years), and tactical actions (current year).

Excellence in Science and Technology

The scientific and technological capabilities of any national laboratory are the essence of its character. At ORNL, we have an extraordinarily broad and deep suite of skills that serves all of DOE's missions. Building on ORNL's rich history, we intend to expand our capabilities in the future in well-defined areas tied directly to DOE's Strategic Plan, research and development (R&D) portfolios, and science and technology roadmaps. We will focus on five major scientific areas.

- **Neutron sciences.** ORNL is positioned to become the world's premier research center for neutron sciences. Construction of the Spallation Neutron Source and the ongoing upgrade of the High Flux Isotope Reactor will provide advanced tools for neutron scattering. These new capabilities will advance DOE missions in broad areas of materials science, chemistry, biology, and engineering. The facilities will be a national resource in the neutron sciences, hosting more than a thousand scientific users each year from universities, industry, and government laboratories. The Joint Institute for Neutron Sciences, to be housed in a new facility funded by the state of Tennessee, will enhance the development of the neutron sciences through partnerships, educational activities, and user support infrastructure. The combination of these facilities, ongoing ORNL research programs, and scientific contributions from users and Laboratory staff will help achieve this vision.
- **Complex biological systems.** ORNL is focusing its extensive resources in functional genomics and proteomics, structural biology, plant sciences, microbiology, computational biology and bioinformatics, and analytical technology on understanding complex biological systems. This effort will extend from molecular and genomic levels through single-cell systems to human biology and physiology to the complex interdependences between living organisms and their environments. Our Complex Biological Systems Initiative will benefit from the Department's plans to make a significant investment in a new Center for Biological Sciences at ORNL, beginning in FY 2001 with the construction of the Laboratory for Comparative and Functional Genomics. This facility will provide a new home for ORNL's mouse colony, bringing this important resource to our main site and replacing an aging and inadequate facility at the Y-12 National Security Complex. Also planned is the construction of a facility, funded by the state of Tennessee, to house the Joint Institute for Biological Sciences.

- **High-performance computing.** Our Terascale Computing and Simulation Science Initiative supports the Department's needs in high-performance computing, networking, and simulation science. ORNL maintains one of the most powerful unclassified computing centers in the world, enabling researchers to solve problems of unprecedented complexity leading to new scientific discoveries. This initiative involves continued development, integration, and application of advances in computer science, high-performance algorithms, software tools, and computational capabilities to solve challenging scientific and engineering problems. It also includes the construction of a facility, funded by the state of Tennessee, to house the Joint Institute for Computational Sciences.
- **Energy and environmental sciences.** Our Energy and Environmental Systems of the Future Initiative addresses the broad challenge, put forward in the Department's mission statement, of fostering "a secure and reliable energy system that is environmentally and economically sustainable." This initiative marshals ORNL's extensive capabilities for R&D on energy production, distribution, and use and for research on the effects of energy technologies and decisions on the environment and society. It focuses on emerging challenges in carbon management, energy systems, and environmental and social systems. This initiative will sustain ORNL's position as DOE's major energy laboratory, providing comprehensive, coordinated support across energy efficiency and fossil, fusion, nuclear, and renewable energy. As DOE's major carbon management science and technology resource, we will expand our R&D on distributed energy resources for energy efficiency in the near term (now–2010), bioenergy for clean power in the middle term (2010–2020), and fundamental scientific breakthroughs for carbon sequestration and environmental modeling to build the science base for the future (2020 and beyond).
- **Advanced materials.** A new initiative in advanced materials will sustain ORNL's position as a world-class materials R&D laboratory supporting DOE missions. A key aspect of this initiative is the development of a program, supported by an investment of Laboratory Directed R&D (LDRD) funds, in nanoscale science, engineering, and technology. This program supports both the National Nanotechnology Initiative, announced by the White House in January 2000, and the Department's continuing efforts to advance the fundamental understanding of nanoscale phenomena through experiment, theory, and simulation. The Advanced Materials Initiative supports the development of new methods for predicting these phenomena and for extending the ability to design, synthesize, and characterize materials at the atomic level, leading to new and enhanced functionality. Also included is a proposal to construct a new Advanced Materials Characterization Laboratory to provide the high-quality environment needed for the sophisticated characterization equipment that is essential to the next generation of materials R&D.

Excellence in Laboratory Operations and ES&H

Continuing the sfe, secure, and cost-efficient operation of ORNL will depend on three initiatives. Modernizing the infrastructure of ORNL is an essential element of our new strategy. We simply cannot continue to conduct cutting-edge research in World War II–era buildings. The poor condition of the physical plant at ORNL is a leading ES&H concern, extends the need for site security beyond what should be necessary, and adds considerably to overhead costs in terms of energy consumption, maintenance, etc. The creation of a new ORNL "campus" will depend upon continued support from DOE programs, the commitment by the state of Tennessee to build four new buildings at ORNL, and new and novel financial arrangements to be enabled by UT-Battelle that will permit private sector development of three new facilities.

This Facilities Modernization Initiative received a major boost in September 2000, when Secretary of Energy Bill Richardson visited ORNL (see Fig. 1.1) to announce DOE's plans to invest $125 million in the new campus. In combination with plans for $25 million in state funds and $50 million in loan guarantees from Battelle, this investment will support the construction of 10 major facilities and the renovation of several others over the next 5 years. When construction and renovation are completed in 2006, ORNL will have replaced 1.8 million square feet of aging and outdated space with about 600,000 square

Figure 1.1
Secretary of Energy Bill Richardson, Tennessee Governor Don Sundquist, Congressman Zach Wamp, and Congressman Bob Clement unveil an artist's conception of ORNL's new campus.

feet of modern, energy-efficient buildings that will support cutting-edge research programs, enhance our ability to work with scientists and engineers from other institutions, improve safety, and reduce the cost of operations, thus contributing to our second major operational initiative—maximizing research effectiveness.

Driving down the cost of doing business at ORNL has surfaced as the leading concern of both our staff and our programmatic customers. Providing maximum R&D per dollar spent at ORNL is one of our key goals. Specifically, we are working to reduce indirect costs by $30 million by the end of FY 2003. To help us attain this goal, we are implementing a two-part workforce restructuring program. The first phase is a voluntary reduction-in-force (RIF) program, to be followed by an involuntary RIF program as needed. We will also take action to streamline our business operations and to attract and retain employees with critical skills for mission execution.

Enhancing the discipline of our operations is the third initiative that we are undertaking in order to deliver on our commitment to excellence in operations and ES&H. Through the implementation of a chemical reuse program, a shift to a landlord/tenant model for facility operations, and the deployment of a Standards-Based Management System, we will set in place the necessary systems and management leadership to enhance overall ES&H and operational performance. We will also stress the importance of rigorous self-assessment to drive continuous improvement in all that we do.

Excellence in Community Service

We will demonstrate our commitment to excellence in community service by contributing to the community as a good neighbor, a resource for knowledge and technology, and a valued partner in education and economic development. Community involvement is expected from members of the UT-Battelle Leadership Team and encouraged for all employees. We are expanding ORNL's participation in state and regional economic development groups. We have established, in partnership with Technology 2020, a regional Center for Entrepreneurial Growth. We are also fostering local economic growth by establishing innovative research partnerships and increasing our technical assistance to businesses and industry. Partnerships with schools and universities likewise will be expanded, with a focus on the six UT-Battelle "core" universities (Virginia, Virginia Tech, Duke, North Carolina State, Georgia Tech, and Florida State), to broaden access to ORNL's resources. UT-Battelle is supporting science education by funding the purchase of new equipment for science laboratories in area schools and increasing opportunities for Tennessee teachers at the Academy for Teachers of Science and Mathematics at UT. We are also working with the community to secure the future of the American Museum of Science and Energy.

Partnerships

A central theme in this new plan is partnerships. We have been encouraged by the strong partnership between ORNL and DOE, both in Headquarters and with the local Oak Ridge Operations Office. The new relationship with the state of Tennessee holds the potential for creating a fundamentally new federal-state partnership based around national laboratories. The partnerships with our six "core" universities and Oak Ridge Associated Universities, which have committed both personnel and funding to expand the research programs and faculty/student interactions between these outstanding research universities and ORNL, promise to take national laboratory–university relations to a new level. We intend to broaden these partnerships to include other universities. New partnerships with local and regional economic development agencies should create greater leverage of federal research funding toward local economic development. Finally, new and mutually beneficial partnerships with other prime contractors across the Oak Ridge Reservation will allow for maximum synergy at this complex site.

William J. Madia
Director,
Oak Ridge National Laboratory

ORNL in the 21st Century

These are exciting times for ORNL. We have a major scientific facility under construction and a host of opportunities to apply the Laboratory's strengths to emerging challenges in science, energy, environmental quality, and national security. We look forward to delivering on UT-Battelle's commitment to simultaneous excellence in science and technology, Laboratory operations and ES&H, and community service as we guide ORNL to a bright future.

2 • Mission and Roles

2.1 • Mission Statement

The Oak Ridge National Laboratory (ORNL) is a multiprogram science, technology, and energy laboratory with distinctive capabilities in materials science and engineering, neutron science and technology, energy production and end-use technologies, mammalian genetics, environmental science, and scientific computing. In support of the missions of the U.S. Department of Energy (DOE), ORNL conducts basic and applied research and development (R&D) to create scientific knowledge and technological solutions that

- strengthen the nation's leadership in key areas of science;
- increase the availability of clean, abundant energy;
- restore and protect the environment; and
- contribute to national security.

ORNL is managed for DOE by UT-Battelle LLC, a partnership between the University of Tennessee (UT) and Battelle.

Figure 2.1
Entrance to Oak Ridge National Laboratory.

2.2 • Mission Roles

As a multiprogram national laboratory, ORNL carries out R&D in support of all four of DOE's major missions: science, energy resources, environmental quality, and national nuclear security. As described in the *Strategic Laboratory Missions Plan—Phase I* (Laboratory Operations Board, U.S. Department of Energy, July 1996), the Laboratory plays a principal role in fundamental science and energy resources and has a specialized participating role in environmental quality and national nuclear security.

2.2.1 • Key R&D Activities

2.2.1.1 • Science

ORNL's R&D in science supports the delivery of the scientific advances and technical innovations that enable DOE to carry out its missions. The Laboratory conducts R&D for DOE in basic energy sciences, biological and environmental research, fusion energy sciences, advanced scientific computing research, and nuclear physics. Activities span the following fields:

- Materials science and engineering, with emphasis on development of ceramics and composites, metals and alloys, carbon-based materials, surfaces and thin films, polymers, and high-temperature superconductors; nanoscale science and engineering; and new techniques for materials synthesis, processing, and characterization
- Neutron science, with strengths in neutron scattering, isotope production, and design and operation of accelerator-based and reactor-based neutron sources
- Life sciences, with emphasis on functional genomics and proteomics, biotechnology, bioengineering, computational biology, and bioinformatics
- High-performance computing, with emphasis on computer and computational science, distributed computing, networking, and intelligent systems

- Environmental sciences, spanning ecosystem research and global change science, environmental processes science and technology, microbial ecology and genomics, plant sciences and genomics, ecological management science and technology, renewable resources R&D, and environmental data systems
- Separations and analytical chemistry, chemical sciences, and chemical engineering technology, with activities in separations science, hydrothermal solution chemistry and geochemistry, actinide science and radioactive materials characterization, isotope separations, computational chemistry and chemical engineering, integrated chemical and bioanalytical instrumentation, miniaturization of chemical reactions and separations, mass spectrometry, environmental monitoring and technology, materials chemistry, fundamental chemistry of energy production and use, and interface and surface science
- Fusion science and technology, spanning plasma theory, magnetic confinement experiments, plasma heating and fueling, atomic physics, and materials development
- Studies of the fundamental properties of matter at the atomic, nuclear, and subnuclear level, focusing on (1) nuclear structure physics and nuclear astrophysics with radioactive ion beams; (2) relativistic heavy-ion beam physics, aimed at the creation and characterization of the quark-gluon plasma; and (3) atomic, molecular, and optical physics
- Instrumentation and measurement science and technology
- Social sciences, providing support for planning and policy decisions related to major energy and environmental issues

DOE's Office of Science (DOE-SC) is the largest single sponsor of R&D at ORNL. The Laboratory carries out work for the Offices of Basic Energy Sciences (KC), Biological and Environmental Research (KP), Advanced Scientific Computing Research (KJ), Fusion Energy Sciences (AT), and High Energy and Nuclear Physics (KA, KB). Other sponsors of R&D in science include the National Aeronautics and Space Administration, the U.S. Department of Defense, the U.S. Department of Health and Human Services, and the National Science Foundation.

2.2.1.2 • Energy Resources

ORNL's in-house energy programs, the largest and most broadly based among the DOE national laboratories, span basic and applied research, technology development, technical assistance, and management of energy-related information. These programs link the physical, engineering, environmental, economic, and social sciences to provide not only new science and technology but also frameworks for improved performance in technology development and deployment, analyses of environmental externalities connected with energy production, and insights for planning and policy decisions related to major energy and environmental issues. Key focus areas are the following:

- Energy-efficient technologies for buildings, industrial, transportation, and utility end-use
- Biomass energy, with a focus on sustainable biomass feedstock and conversion technologies
- Distributed energy resources, emphasizing integrated systems and utility reliability
- Carbon sequestration R&D
- Fossil energy, emphasizing applied materials, fuel cells, and efficient turbine systems
- Nuclear technology and safety

Most of this work is sponsored by DOE's Offices of Energy Efficiency and Renewable Energy (EB, EC, ED, EE, EH, EK, EL, WB), Fossil Energy (AA, AB, AC, AW, AZ, SA), and Nuclear Energy, Science and Technology (AF, AJ, ST). Other sponsors include the U.S. Department of Transportation, the U.S. Department of Defense, the Nuclear Regulatory Commission, and the Environmental Protection Agency.

2.2.1.3 • Environmental Quality

ORNL supports the cleanup of DOE's environmental legacy through the integration of capabilities in analytical chemistry, biochemical engineering, bioremediation, biotechnology, chemical separations, earth and ecological sciences, environmental chemistry and engineering, geological sciences, instrumentation and measurement science and technology, and robotics and intelligent machines. Key R&D activities include the following:

- Environmental management science
- Environmental technology development
- Life-cycle analysis and health and environmental risk assessment

DOE's Office of Environmental Management (DOE-EM) provides funding to ORNL for basic and applied research, development, demonstration, and technical support to address environmental management problems, principally at DOE sites, with increasing emphasis on technology transfer. Work that supports waste management and remedial action projects at DOE's Oak Ridge, Paducah (Kentucky), and Portsmouth (Ohio) sites is coordinated with Bechtel Jacobs Company LLC, which manages DOE's Oak Ridge environmental management program under a management and integration contract. Much of the R&D, however, serves more than one DOE site. DOE's Environmental Management Science Program, a collaborative initiative of DOE-EM and DOE-SC, sponsors basic research to address long-term technical issues and solve challenging problems presented by DOE's environmental legacy. ORNL also performs work for the Environmental Protection Agency.

2.2.1.4 • National Nuclear Security

ORNL contributes to DOE's mission of reducing the global nuclear danger through national nuclear security, nuclear safety, and nonproliferation activities through efforts in three areas:

- Management and disposition of weapons-related nuclear material
- Promoting nonproliferation and international nuclear safety, with a growing emphasis on reducing the threat from biological, chemical, and nuclear agents
- Strategic computing for safe stockpile stewardship

Funding from the Office of the Deputy Adminstrator for Defense Programs (DOE-DP) in DOE's National Nuclear Security Administration (NNSA) supports nuclear weapons R&D, strategic computing, facility transition, and the Accelerator Production of Tritium (APT) program.

The NNSA Office of the Deputy Adminstrator for Defense Nuclear Nonproliferation (DOE-NN) supports R&D activities and technical assessments related to national security requirements (GD, GJ, ND). Much of this work is performed through partnerships with the Y-12 National Security Complex. The DOE-NN Office of Fissile Materials Disposition (MD) supports the development of nuclear-based technologies for fissioning surplus plutonium in power reactors and efforts to dispose of surplus ^{233}U.

Other sponsors of work related to national security include the DOE Offices of Counterintelligence (CN), Intelligence (IN), and Security and Emergency Operations (SO); the U.S. Department of Defense; the Federal Aviation Administration; the Federal Emergency Management Agency; the Federal Bureau of Investigation; and other government agencies with a focus on intelligence collection and analysis.

2.2.2 • Other Activities

ORNL produces isotopes for use in industry, medicine, and research; provides technical leadership and field management to DOE programs; operates information analysis centers; serves as a national repository for ^{233}U; and performs other tasks, frequently on an ad hoc basis, for DOE organizations.

ORNL transfers the knowledge and technology that are the products of its R&D to the private sector through a variety of mechanisms, including partnerships, personnel exchanges, and licensing of intellectual property.

ORNL actively supports the education of the next generation of scientists, engineers, technicians, and educators through a variety of programs for students and faculty at all academic levels.

2.2.3 • Major Facilities

An important part of DOE's science mission is conceiving, constructing, and operating large-scale, complex facilities for R&D. ORNL is home to 16 designated national user facilities (more than any other national laboratory) that are available to laboratory, industrial, and academic users; it also operates a number of other facilities that are used in executing DOE missions. Major facilities include the following.

- **Spallation Neutron Source (SNS).** The SNS, an accelerator-based neutron source now under construction by a team of DOE national laboratories, will be the world's most powerful facility for pulsed neutron scattering research when it is completed in 2006.
- **High Flux Isotope Reactor (HFIR).** The HFIR is among the world's most powerful research reactor facilities. At its current operating power of 85 MW, it has a peak thermal neutron flux of 2.6×10^{15} neutrons per square centimeter per second, highest in the world. This gives the reactor unique capabilities for producing important radioisotopes and providing facilities for materials irradiation, neutron activation analysis, and neutron beam scattering studies.
- **Holifield Radioactive Ion Beam Facility (HRIBF).** The HRIBF is the first U.S. radioactive ion beam facility devoted to nuclear structure and nuclear astrophysics research. It is providing new information on nuclear properties and allowing researchers to make pioneering advances in understanding novas, supernovas, X-ray bursts, and other stellar explosions.
- **Mouse Genetics Research Facility (MGRF).** ORNL's MGRF employs expertise in mouse genetics and mutagenesis, phenotype screening, and high-throughput analytical technologies to generate and analyze mutations that add functional information to specific human DNA sequences. Its extensive stocks of mutant mice are a matchless resource for advancing the understanding of the complex mechanisms underlying the development and functioning of biological systems.
- **High Temperature Materials Laboratory (HTML).** The HTML houses several dedicated laboratories and special equipment for collaborative research on advanced ceramics and alloys. Extensive capabilities for materials characterization support advanced research by a broad user community representing DOE, universities, and industry.
- **Oak Ridge National Environmental Research Park (NERP).** ORNL resources for environmental research and education include the ~8,000-ha (~20,000-acre) NERP, which encompasses a sizable area of protected eastern deciduous forest that contains a number of rare and endangered plant and animal species and several major research facilities: the Walker Branch Watershed, the Throughfall Displacement Facility, the Global Climate Change Experimental Chambers, the Free Air Carbon Dioxide Enrichment Facility, specialized hydrology field research sites, and the Natural and Accelerated Bioremediation Research (NABIR) Program Field Research Center.
- **Buildings Technology Center (BTC).** Research on building thermal envelope systems and materials is conducted in the BTC, which provides world-class facilities for testing advanced building materials and construction strategies.
- **Radiochemical Engineering Development Center (REDC).** The REDC facilities provide transuranium actinide elements (Np, Pu, Am, Cm, Bk, Cf, Es, and Fm) for research endeavors at DOE national laboratories and installations, academic institutions, and industrial facilities.
- **Surface Modification and Characterization Research Center (SMACRC).** The SMACRC is used for fundamental studies of ion-solid interactions and ion beam and laser processing for advanced thin-film science and technology.
- **Shared Research Equipment (SHaRE).** The SHaRE program provides microanalytical facilities for studies in the materials sciences.

2.2.4 • Major Partnerships and Collaborations

ORNL uses partnerships as a means of conducting collaborative R&D and performing work for customers other than DOE; of transferring technology to industry and assisting in its commercialization; and of supporting the education of the next generation of scientists and engineers.

R&D partnerships and collaborations are described in detail in Sect. 6. Work for other sponsors, which helps ORNL to maintain the R&D expertise available to DOE and broadens the application of the Laboratory's strengths to mission-related needs, is described in Sect. 5.6, with detailed descriptions of ongoing work provided in the Supplemental Information appended to this report. Technology transfer and economic development activities are described in Sect. 8.1, and education partnerships are discussed in Sect. 8.2.

Figure 2.2
Students visiting the ORNL Environmental Sciences Division.

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3 • Laboratory Strategic Plan

UT-Battelle's plan for the Oak Ridge National Laboratory (ORNL) is guided by a commitment to achieving simultaneous excellence in the areas of science and technology; laboratory operations and environment, safety, and health (ES&H); and community service, as indicated in Fig. 3.1. The UT-Battelle Leadership Team has developed a Laboratory Agenda to provide a structured framework for the long-term initiatives, critical outcomes, and near-term actions through which it will deliver on this commitment.

Expectations and assumptions about the world in which the Laboratory operates are presented in Sect. 3.1, and the Laboratory Agenda is discussed in Sect. 3.2.

Our major research initiatives are described in detail in Sect. 4, where we also show how they contribute to the missions of the Department of Energy (DOE). Section 5 provides descriptions of the ORNL research and development (R&D) programs that support DOE missions, and Sect. 6 discusses our use of R&D partnerships. Section 7 summarizes our strategy for maintaining and operating the facilities and carrying out the support functions required for mission accomplishment, and Sect. 8 outlines our plans for community service.

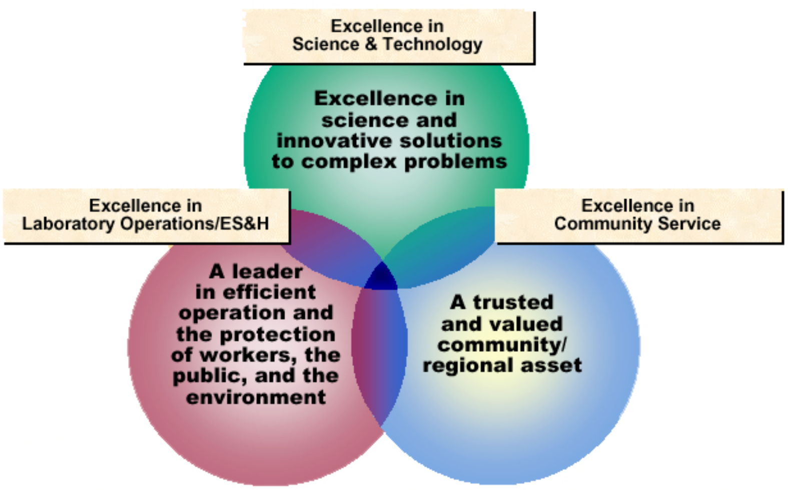

Figure 3.1
The UT-Battelle commitment to simultaneous excellence.

3.1 • Strategic View

We envision expanding opportunities in "science at the boundaries"—the linking of different disciplines to address scientific and technical challenges with far-reaching implications. For ORNL, many of these opportunities will be found in issues surrounding energy—its fundamental nature, its sources, its production and use, and its effects on human health and the environment.

We expect that ORNL will remain a government-owned, contractor-operated multiprogram national laboratory, with DOE as its primary sponsor. In its work for DOE, ORNL will continue to play a principal role in science and energy resources and to apply specialized capabilities to support the Department's needs in environmental quality and national nuclear security. The integration of complementary capabilities distributed across DOE's national laboratory system, through traditional collaborative arrangements and increasingly through advanced "collaboratories" that link distant resources and support remote experimentation, will be a key to the advances in science and technology needed to achieve DOE's strategic goals.

Work for other sponsors will continue to be a significant part of our portfolio. We will actively seek new opportunities to apply ORNL's expertise and capabilities to the needs of other federal agencies and other customers in both the public and the private sector as a means of increasing the transfer of knowledge and technologies to the marketplace, improving the utilization of facilities and expertise, maintaining specialized capabilities, and broadening the Laboratory's funding base.

Partnerships with universities, private industry, state and local governments, and international organizations will continue to strengthen and extend Laboratory programs while expanding access to qualified users of ORNL's resources and facilities. Collaborative relationships that extend across agencies and institutions will be a key to the efficient delivery of R&D that addresses emerging national priorities in such areas as computing and communications, environmental protection, health care, manufacturing, national safety and security, and transportation.

We will maintain our focus on continually improving ORNL's ability to operate safely, securely, and efficiently at reasonable cost while delivering on our mission assignments. Critical assets—including a diverse and talented staff, state-of-the-art research facilities, and specialized capabilities—will be protected and enhanced. The Oak Ridge Reservation land area, which represents an irreplaceable resource, will continue to be retained by DOE to meet near-term and long-term programmatic needs. The Laboratory's Integrated Safety Management System will ensure that safety considerations are fully integrated into the planning and execution of all research and support activities. The performance-based contract between DOE and UT-Battelle will provide explicit measures for assessing the quality of the Laboratory's work.

Concerns about the performance and productivity of the federal government, which gave rise to the Government Performance and Results Act of 1993 (GPRA), will continue. DOE's Strategic Plan and Strategic Management System, which respond to GPRA requirements, as well as the strategic plans of DOE programs, the R&D portfolios for each of DOE's business lines, and the roadmaps developed for critical technologies, will guide and direct our strategic planning.

The increasing prominence of policy issues with a significant science and technology component—such as the threats posed by weapons of mass destruction, the possible effects of human actions on the global climate, and growing demands for energy in developing nations—will sustain the growing recognition that science and technology can boost economic growth, strengthen national security, and improve human health and the environment. Despite support for R&D as a contributor to national well-being, however, discretionary resources for federally funded R&D are not expected to grow substantially, and competition for these scarce resources will remain intense.

Clearly, the availability and stability of funding for major initiatives and core programs will be the most important factor in our ability to carry out our Laboratory Agenda. Other external factors that will affect ORNL's future include the following:

- Explorations of the natural world at the level of the atom, the quantum, and the gene will produce dramatic advances in science and technology.
- Modeling and simulation will become increasingly important in many scientific fields, drawing on and driving advances in computational science and computing power.
- Growing evidence for changes in global climate as the result of human actions, coupled with increases in world population and energy demand, will create a major impetus for broadly based R&D programs to understand the effects of global climate change on ecosystems and society, increase energy efficiency, create new sources of clean energy, manage carbon emitted from the global energy system, and reduce greenhouse gas emissions.
- The national energy system is undergoing a significant transition in response to changes in regulatory frameworks, waste management requirements, alternative energy costs, and other factors. The transition to a deregulated electricity industry will offer opportunities for increased deployment of renewable energy technologies, nuclear power, and other clean energy systems, but it will also

heighten concerns about the cost, reliability, safety, and environmental impact of systems for the production, transmission, and distribution of energy.

- The nation's increasing dependence on interconnected critical infrastructures (e.g., banking and finance, energy, telecommunications, transportation, water systems, and essential government services) will create a demand for new and better forms of protection against physical and cyber threats.
- In an increasingly technological society, lifelong learning about science, mathematics, engineering, and technology through formal and informal education will be essential.

3.2 • Laboratory Agenda

The Laboratory Agenda (see Fig. 3.2) is focused on the most significant activities that UT-Battelle must accomplish to deliver on its vision of simultaneous excellence in science and technology, Laboratory operations and ES&H, and community service. The Laboratory Agenda includes clear statements of the primary results that will be delivered to DOE over the next few years, as documented below.

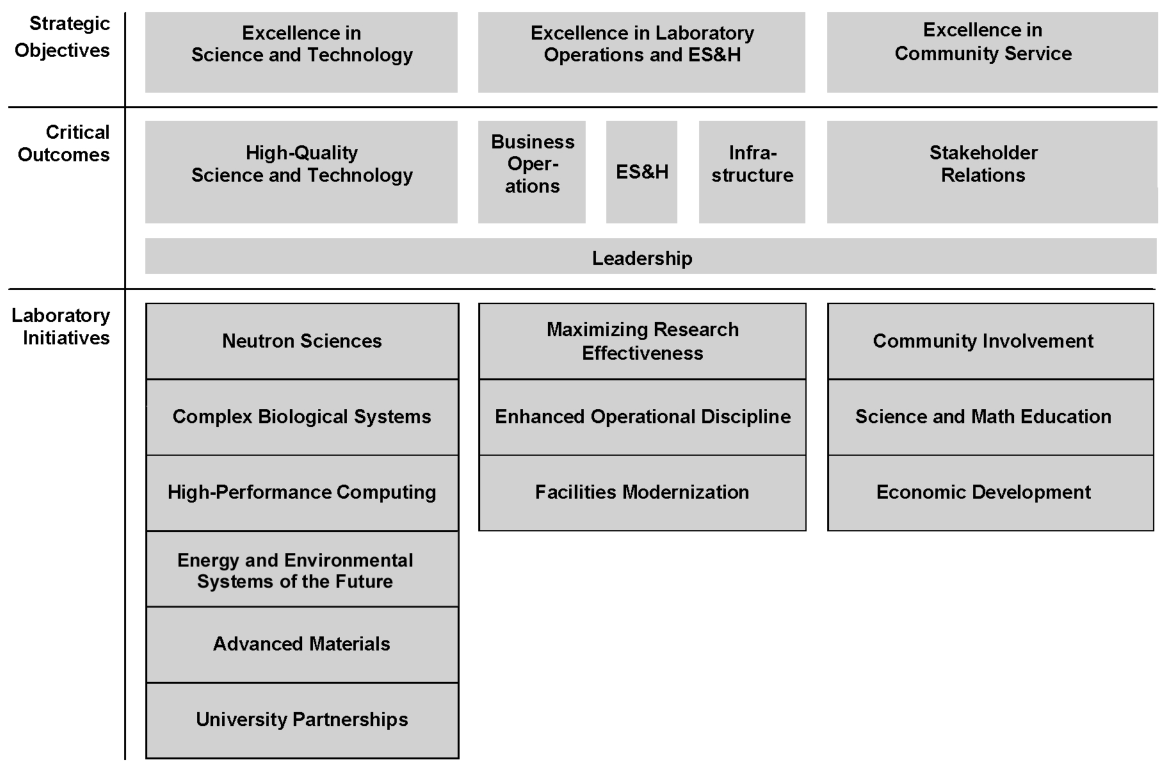

Figure 3.2
Major elements of ORNL's Laboratory Agenda.

Strategic Objective 1: Excellence in Science and Technology

We will prepare the Laboratory to address future national needs for science and technology through major initiatives that sustain and extend its distinctive capabilities. ORNL will also continue to deliver scientific advances and technological innovations in support of DOE's missions and to make its knowledge and expertise available to non-DOE customers.

1. Neutron Sciences. ORNL will become the world's foremost center for neutron sciences by enhancing its capabilities and applying them to deliver new insights into the nature, structure, and behavior of materials.

We are committed to the following actions.

- Deliver the Spallation Neutron Source (SNS) project on schedule and within budget.
- Upgrade the capabilities of the High Flux Isotope Reactor (HFIR).
- Develop innovative research programs that take advantage of the unique capabilities afforded by these facilities.
- Build a world-class user program that provides access to these capabilities.
- Construct a facility, funded by the state of Tennessee, for the Joint Institute for Neutron Sciences.

2. Complex Biological Systems. ORNL will be a center of excellence and a resource for understanding complex biological systems, from the molecular level to the level of the organism, and the interactions of organisms with the environment. Innovative means for observing and understanding the functioning of complex biological systems are developed and applied to meeting DOE's needs in systems biology and environmental quality.

We are committed to the following actions.

- Consolidate the Laboratory's life and environmental sciences resources at the main ORNL site.
- Advance structural biology by combining ORNL's resources in neutron sciences, mass spectrometry, and computational biology through the Center for Structural Molecular Biology.
- Address critical issues in functional genomics and proteomics, using ORNL's mutant mouse resources and strengths in mutagenesis, phenotype screening, plant and microbial sciences, computational tools, and analytical technologies.
- Integrate and extend ORNL's resources in computational biology and bioinformatics to advance the modeling of complex biological systems.
- Expand partnerships with other research institutions and with industry.

3. High-Performance Computing. ORNL is developing the terascale computing and simulation science capabilities that will enable it to become a premier high-performance computing laboratory for DOE's science endeavors.

We are committed to the following actions.

- Secure a multi-teraflops computational platform and infrastructure.
- Increase Laboratory expertise in modeling, simulation, numerical methods, and future architectures.
- Enhance the accessibility of high-performance computing power, both within ORNL and for external partners.
- Expand the scope of the Joint Institute for Computational Sciences.

4. Energy and Environmental Systems of the Future. ORNL will be a key provider of the science and technology needed to support DOE's mission of fostering "a secure and reliable energy system that is environmentally and economically sustainable." Its extensive resources for energy and environmental R&D will be focused on understanding the effects of atmospheric carbon dioxide concentrations and developing acceptable options for carbon management.

We are committed to the following actions.
- Deliver science and technology for understanding carbon sequestration.
- Strengthen analytical capabilities for understanding and assessing climate change and its effects on the environment and society and for evaluating carbon management options.
- Expand leadership in energy efficiency R&D.
- Advance R&D on clean power systems science and technology.

5. Advanced Materials. ORNL will sustain its position as a leader in advanced materials science and technology underpinning DOE's energy resources mission.

We are committed to the following actions.
- Expand ORNL capabilities and programs in nanoscale science, engineering, and technology.
- Secure the next-generation Advanced Materials Characterization Laboratory.
- Develop extraordinary tools for materials characterization.
- Extend the Laboratory's synthesis and characterization capabilities to explore soft materials.
- Establish a Joint Institute for Advanced Materials.

6. University Partnerships. ORNL will increase the value of its science and technology through active involvement of university faculty and students in Laboratory programs.

We are committed to the following actions.
- Establish programs with UT-Battelle core universities for joint hires of scientists and engineers, as a prelude to a program with a wider set of universities.
- Work with Oak Ridge Associated Universities to facilitate research partnerships with its member institutions.
- Expand collaborative programs with the University of Tennessee in areas of mutual interest.
- Develop new research partnerships with Tennessee colleges and universities, historically black colleges and universities (HBCUs), and prominent universities across the country.
- Initiate a summer research program for faculty from HBCUs and other minority educational institutions (MEIs).
- Develop the Oak Ridge Center for Advanced Studies to encourage interactions between ORNL researchers and university faculty and students.

Strategic Objective 2: Excellence in Operations and ES&H

We will sustain and improve ORNL's ability to serve the needs of DOE and the nation through responsible stewardship of the resources entrusted to our care.

1. Facilities Modernization. ORNL will construct new facilities and renovate and replace existing facilities to create a modern research campus that enables the conduct of leading-edge R&D.

We are committed to the following actions.
- Implement a Facilities Revitalization Project to design and construct new facilities and renovate, replace, and dispose of existing facilities in support of ORNL mission assignments and objectives.
- Consolidate Laboratory operations at ORNL's main site.
- Redesign the Laboratory's approach to physical security and facility operations to deliver enhanced performance and staff satisfaction.
- Implement the Uranium-233 Inspection and Repackaging Project.

2. Enhanced Operational Discipline. ORNL will enhance its overall operational performance by improving the discipline and integration of its operations and realigning its security posture to better support accomplishment of DOE's missions.

We are committed to the following actions.
- Upgrade the Laboratory's infrastructure.
- Enhance the Laboratory's cyber security effectiveness.
- Demonstrate continual improvement in ES&H performance, building on the Laboratory's Integrated Safety Management program.
- Deploy an integrated set of "systems-based" management systems.

3. Maximizing Research Effectiveness. ORNL will drive down the cost of doing business, providing more resources for discretionary investments in capability development and infrastructure revitalization, while establishing the Laboratory as an employer of choice in the region and in the research community.

We are committed to the following actions.
- Reduce costs by $30 million by achieving a composite cost multiplier of 1.7 by the end of FY 2003.
- Streamline business operations.
- Attract and retain employees with critical skills for mission execution.

Strategic Objective 3: Excellence in Community Service

ORNL will be viewed by its neighbors as a highly valued partner in the region. We will actively participate in improving the quality of science and mathematics education, supporting the community's civic and cultural activities, and contributing to economic growth.

1. Science and Mathematics Education. We will invest in efforts to improve science and mathematics education in Tennessee.

We are committed to the following actions.
- Purchase state-of-the-art science laboratories for area high schools and middle schools.
- Become a premier sponsor of science and mathematics competitions in Tennessee schools.
- Expand opportunities for Tennessee teachers to participate in the Academy for Teachers of Science and Mathematics at the University of Tennessee.

2. Community Involvement. We will be recognized within the region as a good corporate citizen.

We are committed to the following actions.
- Work with stakeholders to develop and implement a plan for the financial stability of the American Museum of Science and Energy.
- Enrich the community through a set of legacy investments.
- Develop a program of employee volunteerism in community activities.

3. Economic Development. We will encourage the formation and growth of businesses that enhance the local economy by drawing on ORNL resources in knowledge and technology and on UT-Battelle investments in economic development.

We are committed to the following actions.
- Establish special terms and conditions in partnership agreements to favor formation or continuation of East Tennessee companies.
- In partnership with Technology 2020, use the Center for Entrepreneurial Growth to support the creation and development of businesses based on ORNL knowledge and technology.
- Expand technical assistance to business and industry.
- Foster the development of an entrepreneurial culture at ORNL.

4 • Major Laboratory Initiatives

To extend the nation's capabilities in key areas of science and technology, the Oak Ridge National Laboratory (ORNL) proposes major initiatives in

- neutron sciences,
- complex biological systems,
- terascale computing and simulation science,
- energy and environmental systems of the future, and
- advanced materials.

These initiatives will enhance ORNL's ability to support the missions of the Department of Energy (DOE), as indicated in Table 4.1. Research topics associated with these initiatives have been identified as target areas for Laboratory Directed Research and Development (LDRD) funding (see Sect. 5.7).

These initiatives are provided for consideration by DOE. Inclusion of an initiative in this plan does not imply DOE approval of or intent to implement the initiative.

Table 4.1
Support for DOE missions

	DOE mission area			
Major Laboratory Initiative	Science	Energy Resources	Environmental Quality	National Nuclear Security
Neutron Sciences	S	M	M	M
Complex Biological Systems	S	S	M	M
Terascale Computing and Simulation Science	S	S	S	S
Energy and Environmental Systems of the Future	S	S	M	
Advanced Materials	S	S	M	M

S = Strongly supportive.
M= Moderately supportive.

4.1 • Neutron Sciences

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; they are uniquely sensitive to the light atoms that make up much of the natural world; and, because they are highly penetrating, they can be used to probe deep inside materials nondestructively, an application of obvious interest to industry, medicine, and the military. In addition, 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 strengths in neutron sciences constitute 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, isotope production, materials irradiation testing, and neutron activation analysis. Research at ORELA concentrates on nuclear astrophysics and basic neutron properties (e.g., neutron electric polarizability). ORELA is also used for measurements that support DOE's Nuclear Criticality Safety Program (see Sect. 5.3) 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. 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 is engaged in a Neutron Sciences Initiative to ensure that the Laboratory continues its stewardship of neutron science in support of DOE's missions. This initiative has two major elements: design and construction of the SNS, a next-generation spallation neutron source facility, in collaboration with five other DOE national laboratories, as described in Sect. 4.1.1, and upgrades and refurbishment of the HFIR, which will greatly enhance the neutron science capabilities of the world's highest-power research reactor and extend its life well into the 21st century, as discussed in Sect. 4.1.2.

In addition, ORNL is preparing to take advantage of these new scientific tools and to integrate neutron science into research programs across the Laboratory. Activities include the development, in collaboration with Oak Ridge Associated Universities and several other research partners, of a proposal for the design and construction of the Oak Ridge Laboratory for Neutrino Detectors (ORLaND), as outlined in Sect. 4.1.3, and the investment of a portion of ORNL's LDRD funds in neutron science (see Sect. 5.7).

4.1.1 • Spallation Neutron Source

The Spallation Neutron Source (SNS) is an accelerator-based, next-generation neutron scattering facility that is under construction on the Oak Ridge Reservation. It will produce neutron beams that are 12 times as intense as those available from any existing pulsed source, enabling researchers to "see" never-before-observed details of physical and biological materials, ranging from high-temperature superconductors to proteins. The SNS is the top-priority project of DOE's Office of Science (DOE-SC), which has committed nearly $287 million through FY 2000 for its design and construction. It will play a key role in supporting DOE's goals and strategies in science.

Neutrons will be produced at the SNS by bombarding a mercury target with 1-GeV protons. The protons will be produced by an accelerator system consisting of a hydrogen ion source, a linear accelerator (linac), and an accumulator ring that delivers pulsed proton beams with an average power of up to 2 MW, at a frequency of 60 pulses per second, to the mercury target. Under these conditions, a typical proton will release 20 to 30 neutrons through a nuclear reaction process called spallation. The neutrons will be slowed to useful energies in water or supercritical hydrogen moderators and guided into experimental areas, where they will be used in neutron scattering experiments. When operational, the SNS will serve 1000 to 2000 users each year; thus, its performance requirements and instrumentation needs are being determined in close collaboration with the scientific user community.

The SNS project began in FY 1996, when DOE's Office of Energy Research (now DOE-SC) directed ORNL to initiate research and development (R&D) and conceptual design studies. To carry out these studies, ORNL formed a collaborative arrangement with four other national laboratories: Argonne, Brookhaven, Lawrence Berkeley, and Los Alamos. This SNS collaboration, which will continue through the project's construction and commissioning, accesses DOE's best technical expertise and newest technologies, as well as its vast experience with user programs involving scientists and engineers from universities, industry, government laboratories, and institutions in other nations. In March 2000, the Thomas Jefferson National Accelerator Facility joined the SNS partnership.

Workshops and meetings of researchers who use neutron scattering techniques provide valuable input from the scientific community. The most recent SNS Users Meeting was held in Washington, D.C., May 22–24, 2000.

The SNS conceptual design report (CDR) was completed in May 1997. Extensive reviews of the CDR endorsed the SNS partnership, its reference design, technical scope, cost, schedule, and collaborative management approach.

Title I design and construction activities began in October 1998. The final environmental impact statement (DOE/EIS-0247) analyzing the proposed ORNL site and alternative sites for the SNS was completed in April 1999, and a Record of Decision identifying Oak Ridge as the preferred site for the SNS was issued in June 1999. Groundbreaking ceremonies for the SNS were held in December 1999, and an open house in April 2000 drew more than 400 interested persons. A contract for SNS excavation was awarded in April 2000, and major excavation and grading are well under way (see Fig. 4.1). Site excavation is more than 60% complete, and Title II design tasks are in progress.

FY 2001 funding for the SNS project is $278.6 million ($259.5 million for construction and $19.1 million for related R&D). Table 4.2 presents the SNS funding profile.

Figure 4.1
The Spallation Neutron Source construction site, October 2000.

Table 4.2
Funding profile for the Spallation Neutron Source by fiscal year
[budget authority (BA) in millions of actual year dollars]

Prior years	1999	2000	2001	2002	2003	2004	2005	2006	**Total**
38.5	130.0	117.9	278.6	291.4	224.5	143.0	112.9	75.0	**1,411.7**

4.1.2 • High Flux Isotope Reactor Upgrades

The High Flux Isotope Reactor (HFIR) is among the world's most important research reactor facilities. At its current operating power of 85 MW, it has a peak thermal neutron flux of 2.6×10^{15} neutrons per square centimeter per second, highest in the world. This gives the HFIR unique capabilities for producing important radioisotopes and providing facilities for neutron scattering, materials irradiation, and neutron activation analysis.

The proposed SNS (see Sect. 4.1.1) will serve many of the needs of the neutron scattering research community and provide significant improvements over existing beam scattering facilities worldwide for many experiments. However, the HFIR will remain the facility of choice for important 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, and to maintain or improve the availability of neutrons to researchers. The HFIR has been in operation for more than 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 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 instruments and components are based on technology that is now more than 30 years old. Thus, replacing some of these instruments and components is both desirable and cost-effective.

The complete HFIR upgrade package would

- improve the HFIR infrastructure for continued operation at high reliability;
- increase the size and intensity of existing neutron beams;
- add a cold neutron source and an experimental guide hall;
- add several thermal neutron beam guides, a thermal neutron guide hall, and new instrumentation;
- add a neutron radiography/tomography facility;
- improve user access; and
- improve isotope production, materials irradiation, and neutron activation analysis capabilities.

The upgrade also supports ORNL's Complex Biological Systems Initiative, as described in Sect. 4.2.2.

The DOE-SC Office of Basic Energy Sciences has identified program funds to complete the new cold neutron source and install it in the HB-4 beam line on the HFIR and to make the necessary modifications to the HFIR to support the thermal neutron beam guides. Coupled with the steady upgrading of instrumentation over the last few years, these changes will make the HFIR the most intense source in the world for thermal neutron research and will make its cold neutron source capabilities competitive with the world's best. These improvements are being coordinated with the routine replacement of the HFIR beryllium reflector, which is scheduled for FY 2001. The HFIR cooling tower will also be replaced in FY 2001.

The capabilities resulting from the addition of the cold neutron source will support world-class fundamental and applied research programs and could provide the key to new discoveries and applications for polymers, plastics, alloys, and biochemical systems (see Sect. 4.5). As a complement to the capabilities of the SNS, they will address important needs of the neutron scattering research community.

The thermal neutron scattering upgrade, to be completed in FY 2002, will include enlarged beam tubes, new monochromator drums, and extension of the HB-2 beam line into the existing HFIR beam hall. The HB-2 extension will provide space for existing neutron scattering instruments displaced by the cold neutron source. A large thermal neutron guide hall, extending the HB-2 beam line to as many as 15 spectrometers using neutron guides, has been proposed. This hall would provide more space for instruments in a low-background area outside the reactor building. It would also increase the number of users that could be accommodated by increasing the number of beams and instruments. Office and laboratory space would be provided in the new hall for outside users and for ORNL researchers.

The upgrade package also includes the addition of two or three hydraulic access tubes and other changes to improve access for radioisotope production, in support of the ORNL isotopes program, and enhancements to the neutron activation analysis mission, such as the addition of a prompt gamma facility and delayed-neutron counting capabilities.

Completion of the thermal neutron (HB-2) guide hall will require approximately $25 million ($1.0 million in FY 2003, $15 million in FY 2004, and $9 million in FY 2005). Other upgrade activities either are already funded or will not begin until after the current planning period.

With these improvements, the HFIR can continue to operate for another 30 years or more and will provide a unique resource for neutron-based science.

4.1.3 • Oak Ridge Laboratory for Neutrino Detectors

The Oak Ridge Laboratory for Neutrino Detectors (ORLaND) Collaboration has been established by ORNL, Oak Ridge Associated Universities (ORAU), and a number of other research partners to capitalize on a unique opportunity, offered by the construction of the SNS, to advance the understanding of neutrinos.

These particles were first proposed in 1930 by Wolfgang Pauli to explain the puzzling continuum spectrum of electrons emitted in beta decay of radioactive nuclei. They are now understood to be the lighter partners of the so-called "leptons," a family of related particles including the electron, muon, and tau. Neutrinos were first identified by Clyde Cowan and Frederick Reines at the Savannah River reactor and are now known to play a key role in the basic energy-producing reaction of the sun, the explosion of supernovae, and the decay not only of radioactive nuclei but also of most subatomic particles that decay by means of the weak nuclear force.

We now believe that neutrinos come in matter and antimatter types and that there is one type of neutrino for each type of electrically charged lepton; that is, there exist electron neutrinos and antineutrinos, muon neutrinos and antineutrinos, and tau neutrinos and antineutrinos. We know that their spin is $\hbar/2$, and we know the form of the force that governs their interactions with other matter. After 70 years, however, we are still not sure whether they have a nonzero rest mass, and we do not know if one type of neutrino can transform into another type. After many years of experiments that set ever more stringent, but negative, limits to these two questions, recent results suggest that neutrinos might in fact be able to change their type, which would require them to have a nonzero mass. These suggestions come from experiments measuring neutrinos emitted by the sun and, most recently, from the Super-Kamiokande experiment in Japan, which is studying neutrinos coming from interactions of cosmic rays in the earth's atmosphere.

The SNS (see Sect. 4.1.1) will send 1.2-GeV protons into a heavy metal target to produce copious numbers of neutrons. One by-product of the neutron production will be the creation of numerous π-mesons. These π-mesons, in turn, stop quickly and decay into muons plus muon neutrinos, followed by the decay of the muons into electrons plus electron and muon neutrinos. Both matter and antimatter neutrinos are formed, but the specifics of the production reactions happen to particularly disfavor the creation of electron antineutrinos. This fact, combined with the high beam power and very short time structure of the SNS, gives rise to the best pulsed source of mega-electron-volt (MeV)–range neutrinos in the world.

The neutrinos that will be produced in the SNS are in an ideal energy range to permit studies of nuclear, solar, and supernova physics. They also provide an important complement to the energy range addressed by higher energy, but much lower intensity, neutrino sources at the Fermi National Accelerator Laboratory and the European Laboratory for Particle Physics (CERN).

Large detectors are required to detect neutrinos because of the very low probability of a given neutrino interacting with matter. (For example, an MeV-range neutrino has a mean free path of about one light-year of lead.)

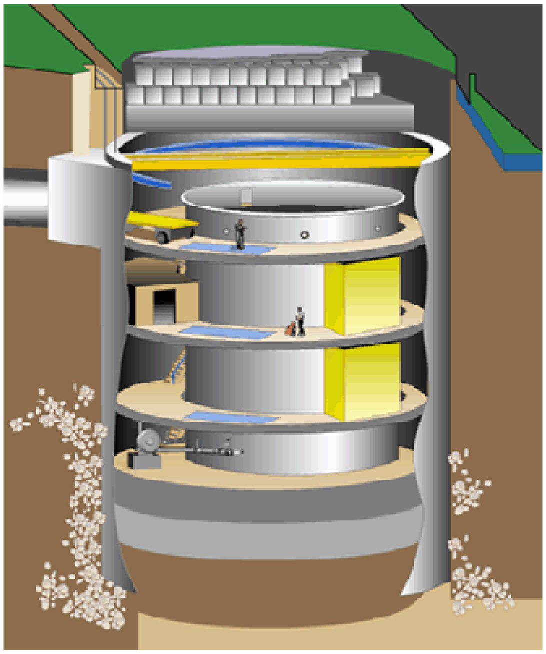

Figure 4.2
Artist's conception of the Oak Ridge Laboratory for Neutrino Detectors.

The proposed ORLaND facility is envisioned as a 10-story bunker, approximately 24 m in diameter and located more than 10 m below ground just outside the SNS Target Hall. It will be heavily shielded to guard against measuring interactions of the copious cosmic-ray neutrinos that constantly bombard the earth.

ORLaND will include space for one large detector nearly 18 m high and 14 m in diameter as the principal detector, plus space for up to five more detectors. The large detector would be filled with 2 kilotons of mineral oil and detect neutrinos by means of the Cherenkov and scintillation light emitted during their interactions. The smaller detectors would consist of 100 to 200 tons of target material, such as a specific metal, interspersed with active elements such as proportional counters to record neutrino interactions with the target material.

In three years of operation at initial SNS design parameters, researchers expect either to confirm the oscillation result from the Liquid Scintillator Neutrino Detector at the Los Alamos National Laboratory, with two orders of magnitude greater statistics, or to significantly extend the oscillation parameter space limits. A proposed second target station, farther from the ORLaND detector, would provide the unique capability of combining two distance measurements from a single detector.

An extensive parallel program of measurements for astrophysics is also planned. Neutrino-nucleus cross sections relevant to nuclear astrophysics would be measured with a small segmented detector in which different nuclear targets could be inserted.

ORNL and ORAU are the lead DOE facilities in the ORLaND Collaboration, which now includes more than 100 scientists. A detailed proposal will be prepared and submitted to the DOE-SC Office of High Energy and Nuclear Physics.

4.2 • Complex Biological Systems

ORNL is developing a significant program in complex biological systems that builds on established programs and expertise in the life and environmental sciences. The Complex Biological Systems Initiative incorporates innovative applications of computational, physical, chemical, and engineering science, as well as special facilities and resources in analytical technologies, to advance the understanding of biological systems. This initiative engages organizations and disciplines across the Laboratory.

Large-scale R&D activities designed to decipher the genomes of various organisms have catalyzed the efforts of teams of researchers whose work crosses traditional disciplinary boundaries. As a result, biological research has been revolutionized by advances in molecular biology, bioanalytical technologies, and computational science. There is now an increasing focus on taking advantage of these new capabilities, and the information gleaned from the genome, to understand the complex interactions, pathways, balances, and control mechanisms of biological systems—from molecular and genomic levels through single-cell systems to human biology and physiology to the complex interdependences between living organisms and their environments.

This initiative draws on programs in comparative and functional genomics, structural biology, and computational biology and bioinformatics. It focuses ORNL's distinctive expertise and facilities in mammalian genetics, biochemistry, environmental microbiology, plant genetics, analytical technologies, computational science and applied mathematics, physical sciences, and engineering on the challenges of observing and understanding the functioning of complex biological systems.

Five key areas will be pursued through the Complex Biological Systems Initiative: comparative and functional genomics, proteomics and structural biology, the microbial cell, biological systems analysis, and predictive toxicology.

Comparative and functional genomics. Molecular and genetic tools are employed to produce mutations in the mouse, and a battery of phenotype screens, computational tools, and analytical technologies are used to establish the function of the affected genes. Novel approaches are being developed to screen animals for new phenotypes, enhance the information obtained, and increase the throughput of phenotype screening. This activity is supported by the Mouse Genetics Research Facility, which includes a colony of over 70,000 animals with a large number of known mutations.

Proteomics and structural biology. ORNL structural biology and functional genomics resources are being employed to understand complex structure-function relationships of proteins in mammals, microbes, plants, and model organisms such as mice, zebrafish, and yeast. Particular emphasis is placed on the identification of modifications in proteins that can affect the formation of protein complexes that are critical to cell signaling processes. This activity is supported by a new user facility, the Center for Structural Molecular Biology, which integrates ORNL's special expertise in biological mass spectrometry, computational biology, and small-angle neutron scattering of proteins and protein complexes.

Microbial cell. Understanding gene function in microbial populations *in situ* integrates genomic approaches for analyzing complicated metabolic pathways, regulatory networks, various cellular processes, and the relationship between microorganisms and their environments. Included in this area is the study of organisms functioning under extreme environmental conditions. Different organisms have unique strengths and weaknesses for studies of different aspects of complex but evolutionarily conserved pathways and systems; as a result, studies of a range of organisms are necessary to understand the below-ground microbial ecosystem. *In vitro* and whole-organism approaches to be used for complex pathway analysis include new experimental and computational methods to produce, exploit, compare, or integrate information from several organisms to explain and understand complex shared pathways.

Biological systems analysis. Biological systems analysis encompasses methods that support systems analysis approaches based on biological data, using genetic and molecular approaches to identify both interactions in networks and temporal changes in the functional roles of specific gene products in cells. Advanced computational algorithms and databases developed over the past decade and new computational platforms that can be used to model organismal physiology and ecosystem dynamics are also of interest. The ORNL Laboratory for Comparative and Functional Genomics, environmental biotechnology capabilities, and computational biology including comprehensive comparative genome analyses and tools for protein classification and structure prediction will be used to advance the modeling and analysis of complex biological systems. The Terascale Computing and Simulation Science Initiative (see Sect. 4.3) will provide new capabilities to support this area.

Predictive toxicology. Scientific advances from the Human Genome Project, subsequent programs in microbial and other genomes, and structural biology provide a foundation for understanding the genetic and molecular basis of toxicology. Predictive toxicology, for both human and animal exposure to chemicals in the environment, can be associated with specific gene systems. Many of these gene systems are evolutionarily conserved, and these gene systems are ubiquitous—thus permitting comparative toxicology.

The Complex Biological Systems Initiative builds on ORNL's previous major initiative in functional genomics and proteomics, through which the Laboratory has developed a strong program in this key area (see Sect. 4.2.1). It also incorporates programs in structural biology (see Sect. 4.2.2), plant and microbial genomics (see Sect. 4.2.3), and computational biology and informatics (see Sect. 4.2.4), and it involves significant collaboration with other DOE laboratories and other institutions. Additional components include the Center for Biological Sciences (see Sect. 4.2.5), which is under development with support from DOE-SC's Office of Biological and Environmental Research (OBER), and the University of Tennessee (UT)–ORNL Joint Institute for Biological Sciences (see Sect. 4.2.6). Funding projections for the Complex Biological Systems Initiative are shown in Table 4.3. (These projections do not include capital funding for the Center for Biological Sciences, which is presented in Sect. 4.2.5.)

Table 4.3
Funding projections for Complex Biological Systems Initiative by fiscal year
(in millions of dollars)

	2001	2002	2003	2004	2005
Functional genomics and proteomics	6.0	8.0	10.0	10.0	10.0
Center for Structural Molecular Biology	1.1	2.0	2.5	3.0	3.0
Plant and microbial genomics	2.0	2.5	3.0	4.0	4.0
Computational biology and bioinformatics	3.0	3.5	4.0	4.0	4.0
Total	**12.1**	**16.0**	**19.5**	**21.0**	**21.0**

4.2.1 • Functional Genomics and Proteomics

The Human Genome Project has produced a "working draft" of the reference human genome, providing the biomedical research community with a computerized catalog of the names, locations, and nucleotide sequences of the more than 80,000 genes on the human chromosomes. Significant advances in the ability to determine the function of genes, within and across genomes, are needed to unlock the information contained in the output from sequencing and gene searches.

Biologists have studied gene function for many years, but much of this research has been slow, costly, and directed at single genes. Access to the powerful reagents from the genome program is changing this situation. In the new era of biomedical research that has just begun, it will be possible to perform experiments in functional genomics—that is, to determine the function of genes and systems of genes on a genome-wide scale.

Gene function is determined (1) by analyzing the effects of DNA mutations in genes on normal development and health in the whole organism; (2) by analyzing a variety of signals encoded in the DNA sequence; and (3) by studying the proteins produced by a gene or system of related genes. Researchers can study functional genomics in humans by using genome information from model organisms, which provide rich scenarios for experimental research. The mouse, with its genetic and physiological similarities to the human and its extensive comparative genetic linkage map, is a leading model organism for determining human gene function. A wide variety of genetic and molecular manipulations are possible in the mouse, making it a powerful research organism for studies of functional genomics.

Other organisms are also being intensively studied. With completed DNA sequences for plants and microbes (see Sect. 4.2.3), researchers have opportunities to work on gene networks and gene interactions in systems where all the genes are known. Work on other model organisms also opens related research areas that are important to DOE, such as the identification of organisms in the environment and the genetic manipulation of organisms to help mitigate environmental problems.

The availability of complete DNA sequences for many organisms also enables whole new lines of scientific inquiry into the nature of the proteome, the proteins encoded by the genome. Thus, an important aspect of determining gene function is the characterization of the vast number of proteins expressed by the genome, including the determination of both the structure of a particular protein and its role in the organism. Proteomics research programs are being planned by DOE and other agencies, drawing on new high-throughput assays to identify normal and modified proteins by mass spectrometry and to determine the structures of proteins and protein complexes with X-ray crystallography, nuclear magnetic resonance (NMR) spectroscopy, mass spectrometry, neutron scattering techniques, and computational tools.

ORNL is combining the unique strengths of its research programs in mouse genetics and mutagenesis with its resources in structural biology and analytical technologies (see Sect. 4.2.2), plant and microbial genomics (see Sect. 4.2.3), and computational biology and bioinformatics (see Sect. 4.2.4) to address critical issues in functional genomics and proteomics. This approach is based on the conviction that genetics and protein studies should be viewed as integral components of an overall strategy to understand protein function in the context of the whole organism and to define this function at the molecular level.

The intent of the Functional Genomics and Proteomics Program is to maximize ORNL's ability to (1) assign both biochemical and organismal function to genes and proteins, (2) define interacting protein pathways at the molecular level, and (3) establish the role of proteins in the whole organism. The focused investment of Laboratory Directed R&D (LDRD) funds in this program from FY 1997 through FY 1999 served to catalyze cross-disciplinary research projects, involving biologists, chemists, engineers, physicists, and computer scientists, to develop the tools required for mounting a highly efficient, comprehensive system for functional genomics and proteomics.

New approaches are being applied to the task of enriching raw DNA sequences, generated at the DOE Joint Genome Institute and elsewhere, with functional information derived from gene expression and protein studies of mutations in the mouse. Researchers are combining advanced methods in mouse mutagenesis with the development of new functional genomics and proteomics technologies, both analytical and computational, to understand how gene expression affects specific biological systems. These technologies are also being used to study important microbial and plant systems (see Sect. 4.2.3).

A key component of the program is the Mouse Genetics Research Facility (MGRF), a DOE user facility that is an unparalleled resource for experimental research in functional genomics. Using the mouse as a model organism, geneticists can "target" a specific gene to eliminate or alter its function in the whole animal or only in a specific cell population, or they can add normal genes back to a mutant mouse to correct an abnormality. They can engineer rearrangements in large regions of the genome and then create gene-by-gene mutations in these regions using the chemical mutagen ethylnitrosourea (ENU) to make single-base changes in DNA. ENU is useful for making multiple different mutant forms of a single gene, thereby providing more exact human disease models that mimic the subtle genetic variations characteristic of human populations. These strategies for creating mutations in mice can easily be expanded to a genome-wide scale, generating genetic reagents essential for the entire research community.

ORNL is melding its advanced technologies and computational biology capabilities with its mouse mutation resources to establish highly efficient techniques for defining specific functions of proteins in mutation models. Work is under way along the following lines:

- Analytical technologies for augmenting primary phenotype screening and secondary/tertiary analyses of mutant phenotypes. Gene expression and protein analysis are facilitated by novel genosensor arrays and new high-throughput mass spectrometry techniques, respectively. Automated, high-throughput phenotype screening techniques are under development, including automated whole-animal imaging devices for mice.
- Technologies to facilitate genetic linkage analyses in large-scale mouse crosses for genetic dissection of complex biological pathways. ORNL will apply its established methods in mass spectrometry to support high-throughput linkage analyses. Complementary technologies, including novel hybridization chips and microfluidic devices, are also being developed.
- *In vitro* and whole-animal approaches for complex pathway analysis. Researchers are investigating a new means for *in vitro* screening for recessive mutations. Chip-based mRNA expression profiling technologies (which can screen for expression of genes involved in cellular processes, such as apoptosis) will be incorporated.
- New techniques for high-throughput detection of variants of specific proteins that can then be used in both genetic (organismal) and structural (biophysical) analyses. ORNL will employ novel high-throughput mass spectrometry–based procedures for carrying out one-generation chemical mutagenesis screens. Results from these "protein variant screens" will then direct the matings of variant mice to reveal both dominant and recessive whole-organism, functional phenotypes.
- Structural characterization of mutant proteins with phenotypic ramifications and comparison with wild type for determination of structure/function relationship. Resources in mass spectrometry and a

new facility for small-angle neutron scattering that is part of the proposed Center for Structural Molecular Biology (see Sect. 4.2.2) will be combined with structural techniques, including synchrotron-based protein crystallography and NMR, available at collaborating national laboratories, and with ORNL's expertise in computational biology (see Sect. 4.2.4).

- Validating predictions of protein structure and function through mouse genetics and mutagenesis. As more genomic DNA sequence data become available from the Joint Genome Institute and other sequencing centers, mouse genetics and mutagenesis, combined with computational analysis, will become a powerful tool for understanding gene and protein function at a number of levels.

As with all actively growing research programs, new directions will become apparent and drive changes in direction; the activities listed here provide an overview of the program and the kinds of information to be obtained.

In summary, the goal of the ORNL Functional Genomics and Proteomics Program is to understand protein function in the context of the whole animal and to define this function at the molecular level by combining advanced methods in mouse mutagenesis with the development of new concepts for functional genomics and proteomics technologies. Although the focus of this effort is not directly related to drug discovery, the developed tools will be applicable to this field. By working with other research institutions, particularly other national laboratories, ORNL will ensure complementarity with related programs in functional genomics and proteomics and will make its resources and technologies available to them.

ORNL will also strengthen existing collaborations, form new collaborations, and serve as a resource to research groups at other national laboratories and in academia and industry. The Tennessee Mouse Genome Consortium supports collaborations with Meharry Medical College, St. Jude Children's Research Hospital, the University of Memphis, the University of Tennessee (in Knoxville and Memphis), and Vanderbilt University Medical Center; a five-year, $12.7 million grant from the National Institutes of Health, announced in October 2000, will support the consortium's neuromutagenesis program. The Merck Genome Research Institute has initiated a research project through the Joint Institute for Biological Sciences (see Sect. 4.2.6), and several new projects are being discussed.

Activities are also under way to establish collaborative efforts with pharmaceutical and biotechnology companies. An R&D consortium involving three industry partners—Abgenix, DNX Transgenics, and CJ America—has been organized by the Gene Research Access Corporation (GENRAC), a nonprofit organization established to enable private-sector sharing in functional genomics research at ORNL and UT. The consortium will focus on identifying new mouse models for human genetic diseases and novel methods to identify disease phenotypes for use in discovery research programs and other purposes of the partners. Work is under way to develop a program that will meet the companies' needs and expectations.

4.2.2 • Structural Biology

Structural biology is a rapidly growing field with a burgeoning impact on basic and applied biology. ORNL will combine its existing strengths in neutron sciences, mass spectrometry, and computational biology and make them available to a broad user community in the biological sciences through the new Center for Structural Molecular Biology (CSMB), which has been funded by OBER starting in FY 2000. The CSMB will be a key component of the proposed Center for Biological Sciences (see Sect. 4.2.5).

The cornerstone of the CSMB is a small-angle neutron scattering (SANS) facility to be constructed at ORNL's High Flux Isotope Reactor (HFIR). SANS is an important tool for studying molecular conformations and interactions. It provides insight into the molecular basis of communication pathways that achieve coordinated function by identifying specific chemical groups that interact with the environment and with molecular networks involved in binding and activation sequences. It also provides information on the dynamics of a biomolecule in solution and complements high-resolution structural X-ray crystallographic data obtained from static, crystalline molecules. SANS will be a key tool for understanding the cellular-level communication that is the basis for protein function and, thus, gene function.

The CSMB takes advantage of the opportunity afforded by the HFIR upgrade project (see Sect. 4.1.2), which includes the construction of the nation's "brightest" long-wavelength neutron source. A SANS instrument and associated resources specifically designed for the study of biological systems can be economically developed and built as part of this upgrade; OBER is providing nearly $6 million for such an instrument, designated Bio-SANS. The Bio-SANS, which should be operational by June 2002, will incorporate both high flux and a large-area (1-m^2) detector to collect data over a wider solid angle to enhance the study of biological molecules. The resulting facility will provide the U.S. biological community with state-of-the-art capabilities in SANS, rivaling the world's best biological facilities at the Institut Laue Langevin in France.

The CSMB also leverages ORNL's well-established biological mass spectrometry and computational resources, providing the biological community with additional tools that complement structural information obtained from SANS. For example, modifications to proteins can profoundly affect both the structure and the function of biomolecules. Mass spectrometry can provide information on both the extent of these modifications and the sites of attachment. Computational modeling can support conformational changes observed with SANS. In addition, for uncharacterized proteins, computational methods can be used to identify fold families and to build models from related known proteins before SANS analysis. Capabilities within the CSMB will complement resources at other structural biology facilities, such as synchrotron X-ray crystallography centers, to provide a more complete picture of the structure of biological molecules and their interactions in complex systems.

The CSMB will extend its capabilities to programs within the DOE community and to other government, academic, and industrial laboratories. An advisory panel of distinguished scientists provides guidance to the director and staff of the CSMB. A CSMB User Group has been created to give advice on equipment and capabilities to be included in the CSMB and to establish guidelines for operation. An important aspect of the CSMB will be the training and education of students and scientists in the technologies within the CSMB. A wide range of opportunities for scientists and students working in the field of structural biology will be provided, including extended visits for experimental work, short courses, workshops, and scientific meetings. The Joint Institute for Biological Sciences (see Sect. 4.2.6) will facilitate many of these collaborative opportunities.

The Bio-SANS facilities at the HFIR will be located as far as possible from other instruments to achieve the low background required for biological studies. Adjacent laboratory facilities will be available for final preparation of samples. Data acquisition and reduction capabilities will be integrated into instruments, and ORNL staff will be available to support users.

CSMB users will also have access to the following resources:

- other neutron-based tools at the HFIR, including another SANS instrument designed for studying materials with higher resolution and a reflectometer that can be used to study biomolecular monolayers and thin films;
- a small-angle X-ray scattering instrument that can be used to evaluate biological samples before SANS experiments;
- resources in biological mass spectrometry, including two high-performance Fourier transform ion cyclotron resonance mass spectrometers and a number of other instruments equipped with electrospray and matrix-assisted laser desorption sources;
- resources in computational biology and informatics (see Sect. 4.2.4), which can be used for modeling, prediction, and database use;
- sample preparation facilities to support SANS and mass spectrometry experiments; and
- support services through the Joint Institute for Neutron Sciences.

In the longer term, the capabilities afforded by the Spallation Neutron Source (see Sect. 4.1) will create new opportunities in structural biology. The Center for Biological Sciences (see Sect. 4.2.5) will serve as the point of coordination for future CSMB activities that draw on these capabilities.

The CSMB fills an important niche in the spectrum of scientific tools required to perform comprehensive structure-function experiments. It is designed with specific interfaces to the neutron crystallography center at Los Alamos National Laboratory so as to jointly serve and grow the structural biology community that takes advantage of the unique features of neutron sources. It is unique in its combination of high-flux cold neutrons for SANS, world-class resources in computational biology, and a pioneering mass spectrometry facility.

4.2.3 • Plant and Microbial Genomics

In parallel with the Human Genome Project, intensive efforts are under way to sequence the genomes of plants, with obvious implications for agricultural crops, and of important pathogenic and environmentally and commercially significant microorganisms. Many smaller genomes have been completely sequenced, providing a wealth of new genetic information. The availability of this information and the development of new tools (e.g., sequencers and robotic systems) that allow for the gathering of genetic information on a large scale are creating new opportunities in plant and microbial genomics at ORNL.

Microbial activities, sponsored by DOE-SC, the DOE Office of Environmental Management, and the Office of the Deputy Administrator for Defense Nuclear Nonproliferation (DOE-NN) within the National Nuclear Security Administration, build on the Laboratory's long-term involvement in environmental monitoring and bacterial isolations. Work in environmental monitoring expanded to include biosensors, now a key area of expertise. Efforts in bacterial isolations identified unique extremophile bacteria that represent resources for future projects and fostered the development of molecular expertise that supports new efforts in functional microbial genomics. Investment of capital resources in equipment for molecular-level explorations also supported the development of expertise and has set the stage for future projects and further expansion into functional genomics. The new Natural and Accelerated Bioremediation Research (NABIR) Field Research Center on the Oak Ridge Reservation (see Sect. 5.1.2) will provide new opportunities to understand the interactions of microbes with groundwater and soil, complementing work on microbial genomics. It will also generate data that can be incorporated into the mathematically based numerical models that are an important tool in predicting and planning groundwater management programs and remediation strategies, and it will provide opportunities for comparing computational predictions of bioremediation techniques with actual outcomes.

Arrays of DNA probes are expected to become a foundation for work on microbial pathways, gene expression, and community structure analysis. ORNL will continue to play a significant role in the development of these DNA arrays, which support work that addresses fundamental questions related to DOE missions. For example, metal-reducing bacteria are of interest for remediation of waste sites, for carbon sequestration (e.g., production of carbonate minerals), and for production of novel materials (e.g., cobalt-doped magnetite). DNA arrays that monitor the expression of all of the genes of an important and versatile strain of metal-reducing bacteria are being constructed. Future applications include monitoring microbial communities, assaying background bacterial populations in the air (needed for work on chemical and biological agents in support of DOE-NN), and supporting the discovery and characterization of infectious agents.

In plant genomics, under the sponsorship of DOE-SC and the DOE Office of Energy Efficiency and Renewable Energy, the complexity of the interactions among metabolic pathways, integrative gene expression, and the environment currently limits our ability to make predictions about individual plant growth and ecosystem responses to the environment. Characterizing gene function through functional genomics and differential display technologies, in combination with conventional studies of plant physiology, ecosystem function, and landscape modeling, provides a means of understanding complex plant-based biological systems. Molecular dissection of complex traits will allow the isolation and use of genes that control environmentally and economically important characteristics. These areas will be developed and explored at ORNL, drawing on the availability of state-of-the-art equipment (e.g., a BI 3700 sequencer) in the development of functional plant genomics.

New tools and approaches in bioinformatics will be needed to deal with new DNA array data and DNA sequence data. Work at ORNL to develop artificial neural networks for pattern recognition is laying the groundwork for processing some of these data. The expansion of this approach from biochemical markers (e.g., specific lipids) to DNA data of various kinds offers promise for increased understanding of the complexity of plant and bacterial communities and their interactions with environmental factors.

4.2.4 • Computational Biology and Bioinformatics

In 1991, Eric Lander, a pioneer in human genome research, remarked, "Biology is in the middle of a major paradigm shift—driven by computing. Although it is already an informational science in many respects, the field is rapidly becoming much more computational and analytical."[1] Today it is fair to say that many large multinational biology research programs—such as the Human Genome Project, other genome sequencing efforts, and emerging proteomics and systems biology programs—simply would not succeed without major investments in computational biology/bioinformatics research and computational infrastructure.

ORNL has a significant program, dating from the early 1980s, in bioinformatics and computational biology. Early successes include GRAIL™ (Gene Recognition and Analysis Internet Link), a gene finding and modeling tool that applies advanced pattern recognition technology and has become a widely recognized standard in gene finding and modeling. The latest development, GRAIL™-EXP, is unparalleled in its ability to accurately find genes in long segments of double-stranded genomic DNA, a capability that is critically important for the analysis of the output of large-scale sequencing.

These and other informatics tools developed at ORNL and elsewhere have been integrated into a high-throughput analysis sequence analysis pipeline, the Genome Channel. This tool examines a DNA sequence and then predicts genome features, including gene models and the resulting protein models. The predicted protein models are compared to databases of existing proteins for similarities in protein sequence; this adds biological meaning to the genome sequence by suggesting the biological function of the genes and proteins encoded by that sequence. The information is regularly recomputed and updated as new data become available. In April 2000, DOE's Joint Genome Institute completed working drafts of human chromosomes 5, 16, and 19. The complete annotated draft data have been incorporated into the Genome Channel, and ORNL staff members are analyzing the sequences computationally to identify the locations of genes within the sequences.

Rapidly characterizing the protein models resulting from genomic sequences includes classification of putative proteins into functional classes, based on sequence information and folding predictions. ORNL researchers are now carrying out a project to assign the maximum amount of structural information to proteins, computationally identified from genes, of the *Prochlorococcus europa* genome, by combining a number of existing methods, including the ORNL-developed PROSPECT (Protein Structure Prediction and Evaluation Computer Toolkit).

The computational biology and bioinformatics effort takes advantage of ORNL's high-performance computing environment. As sequence data rates increase rapidly to unprecedented levels, and as the throughput of the analysis pipeline and computational characterization of proteins keep pace with the sequencing, a high-performance computing infrastructure (see Sect. 4.3) becomes even more critical to the success of this effort. Development of the Center for Biological Sciences (see Sect. 4.2.5) will also improve the linkages between the computational biology and bioinformatics program and the other elements of the Complex Biological Systems Initiative.

4.2.5 • Center for Biological Sciences

OBER is planning for a significant investment in a new Center for Biological Sciences (CBS) at ORNL during the FY 2001–FY 2004 period. The CBS is planned as a modular complex of buildings, equipment, and infrastructure to house current and future research programs in functional genomics, structural biology, proteomics, and systems biology. It will provide the environment for the ORNL biological research program to make significant contributions to biology during the next decade and beyond, with a special focus on complex biological systems research. Development of the CBS will

[1]E. S. Lander, *Computer* **24** (11), 6–13 (1991).

Figure 4.3
The new Environmental and Life Sciences Laboratory nearing completion.

enhance the advantages inherent in the structure of the program, which embraces not only the biological sciences but also allied disciplines in information science and computing, analytical methodologies, and chemistry. Table 4.4 provides funding projections for the CBS.

The initial element of the CBS is the Environmental and Life Sciences Laboratory (see Fig. 4.3), constructed with General Plant Project (GPP) funds. The next phase in the development of the CBS is the construction of the Laboratory for Comparative and Functional Genomics (LCFG), at an estimated cost of $13.9 million, to house the Mouse Genetics Research Facility. The LCFG will replace an aging building at the Y-12 National Security Complex that is no longer adequate to house one of ORNL's premier research facilities. In addition to the mouse colony, the LCFG will include laboratories with special phenotype screening and cryopreservation capabilities, thus supporting the ORNL Functional Genomics and Proteomics Program (see Sect. 4.2.1).

As indicated in Table 4.4, the cost of constructing the LCFG is $13.9 million. The new building will dramatically reduce the cost of operating the MGRF, making it possible to amortize this investment in strict monetary terms in less than three years. The savings in operating cost will also effectively increase the MGRF research budget by more than $1 million per year, providing a significant improvement in ORNL's ability to make cost-competitive R&D proposals to DOE and other federal and nonfederal sponsors and customers.

A Congressionally appointed external independent review (EIR) panel, convened at ORNL in July 2000, concluded that the facility is justified and construction should proceed. The panel also commended ORNL for a "best practice" in the front-end planning for the project, carried out by the ORNL engineering team, in ensuring that critical needs are met. Funding of $2.5 million to initiate LCFG construction is included in the FY 2001 budget.

The CBS will also encompass the CSMB (see Sect. 4.2.2) and the Joint Institute for Biological Sciences (see Sect. 4.2.6). The Spallation Neutron Source beam line identified in Table 4.4 is the principal new capital resource needed to support the CSMB beyond 2003. The State of Tennessee has pledged to provide funding for a facility to house the Joint Institute.

Table 4.4
Capital funding projections for the ORNL Center for Biological Sciences by fiscal year
(in millions of dollars)

	2001	2002	2003	2004	2005
Laboratory for Comparative and Functional Genomics	2.5	10.0	1.4	0.0	0.0
Structural biology beam line for the Spallation Neutron Source	0.0	0.0	3.0	3.0	3.0
Computational biology and bioinformatics	2.0	3.0	0.0	0.0	0.0
Proteomics	3.0	5.0	2.0	0.0	0.0
Instrumentation	2.0	1.0	1.0	1.0	1.0
Total	**9.5**	**19.0**	**7.4**	**4.0**	**4.0**

ORNL's resources in computational biology and bioinformatics (see Sect. 4.2.4) will be enhanced by and contribute to the CBS, which will provide space and "connectivity" (computing and information technology infrastructure) for both the computational biology and bioinformatics researchers and the experimental biologists. The leverage gained through this combination of expertise and infrastructure will also provide tools facilitating the use of the CBS facilities as a virtual laboratory by research partners at other institutions.

Research programs at the CBS will encompass ORNL's important efforts in protein biochemistry, which were recognized in 1998 with the election of a senior staff member to the National Academy of Sciences. The CBS will provide the physical environment for fully integrating these efforts into ORNL's biological research program and bringing them to bear them on the broader charge of proteomics.

Future biological research at ORNL will be aggressively directed to take advantage of advances not only in computational biology but also in instrumentation and measurement sciences and technology. Facilities at the CBS will co-locate bioinstrumentation and bioengineering R&D efforts with the new biological research programs. These programs will build strong alliances with other biological and medical research centers, building on the resources of the Joint Institute for Biological Sciences.

4.2.6 • Joint Institute for Biological Sciences

ORNL and UT have established the Joint Institute for Biological Sciences to promote and develop support for collaborative education and research in biological sciences. UT organizations involved in this effort include the Medical Center, the College of Veterinary Medicine, and the Institute of Agriculture.

The initial phase focuses on strengthening the partnership between ORNL and UT and developing or expanding collaborative efforts in functional genomics, structural biology, and computational biology and bioinformatics. This phase includes the integration of the ORNL-UT Graduate Program for Genome Science and Technology into the Joint Institute. The second phase in the evolution of the Joint Institute will explore new areas such as biomedical engineering (see Sect. 5.1.2).

The Joint Institute for Biological Sciences will provide new opportunities for applying the complementary capabilities of ORNL and UT to emerging problems in the biological sciences. It will also support the integration of research and education, exposing students to the multidisciplinary approaches needed to understand complex biological systems. A strong interface with the UT Medical Center is envisioned to support the effective transfer of R&D results to clinical applications, and distance learning capabilities at ORNL and UT will enhance opportunities for national and international participation in research conducted under the auspices of the Joint Institute. Funding from the State of Tennessee will be used to construct a facility to house the Joint Institute as part of the ORNL Center for Biological Sciences (see Sect. 4.2.5).

4.3 • Terascale Computing and Simulation Science

4.3.1 • New Directions in Computation and Simulation

The use of computational tools is vital to essentially all fields of science and engineering. These tools enable the creation of realistic simulations of physical situations, providing new insights into a host of scientific problems. Indeed, simulation has now joined the traditional approaches of experiment and theory as a fundamental avenue to understanding.

Improvements in computer performance during the past decade have been dramatic—a trend that promises to continue. Massively parallel computers that exploit advances in microprocessor technology offer the enormous computational power needed in solving Grand Challenge problems. Distributed computing, which applies clustered computers to the solution of a single large problem, is a major trend in scientific problem solving. Advances in electronic collaboration and advanced computational and visualization tools are supporting the efficient use of research facilities and the creation of "virtual laboratories."

ORNL has played a leading role in these advances. The Laboratory has been at the forefront in acquiring and evaluating massively parallel computers and bringing them to production status. The worldwide popularity of distributed computing can be traced in large part to ORNL's development of the PVM (Parallel Virtual Machine) software for efficiently linking computers. ORNL has also contributed to advances in parallel code development, in data storage systems and software, and in visualization and networking. The linking of the Intel Paragon computers at ORNL and Sandia National Laboratories to solve formidable computational problems represents success in addressing a range of challenges in wide-area computational grids. ORNL's work on the Electronic Notebook, the Collaborative Management Environment, and the Materials Microcharacterization Collaboratory has contributed to more effective collaborations and more efficient use of DOE resources.

DOE's Scientific Discovery through Advanced Computing (SDAC) Program is being developed to take the nation into a new era of information and communications technology. It will rapidly deploy computing and communications capability that is at least 10 times faster than today's fastest systems for government, academic, and industrial use. This capability will revolutionize current approaches to solving complex problems in energy, the environment, fundamental biological and physical sciences research, and technology development, and it will stimulate the national system of innovation.

Attaining the proposed capability will demand significant advances in computational resources. Fully exploiting the power of massively parallel machines requires the creation of new programming paradigms, languages, scheduling and partitioning techniques, and algorithms, and all of these elements must be integrated into systems that are accessible and useful to a diverse user community.

4.3.2 • ORNL Resources and Opportunities

As DOE's most programmatically diverse national laboratory, ORNL conducts a broad range of theoretical and experimental programs (see Sect. 5). ORNL is also home to a comprehensive computational science effort that leverages extensive expertise in the application of computing to physical problems and excellent facilities for massively parallel high-performance computing to answer scientific questions and to advance the development of computational resources.

The ORNL Computer Science and Mathematics Division (CSMD) is the focal point for the development and application of innovative computational systems and tools. Resources include a 1-teraflops IBM SP supercomputer, a 400-gigaflops Compaq AlphaServer SC system, and a 300-terabyte data storage and access system, offering a computing speed of 1.5 trillion operations per second (teraflops). This terascale computing facility, dedicated in June 2000, provides more than 10 times the computing power of the Intel Paragon XP/S 150, which was the fastest computer in the world in 1995.

Figure 4.4
Dedication of ORNL's terascale computing facility. Left to right: Bill Madia, director of ORNL; Jesse Lipcon, vice president of Alpha Technology, Compaq; Ernest Moniz, DOE Under Secretary for Research and Development; and Thomas Zacharia, ORNL.

In addition to managing this facility, CSMD conducts extensive efforts in parallel code development and in strategies for large-scale cluster computing and maintains a broad range of visualization and networking systems and expertise. CSMD is a world leader in basic research on heterogeneous distributed computing, applied mathematics, statistics and data science, and collaborative technologies. CSMD also carries out basic research in quantum computing, cooperating autonomous systems, and nonlinear science. Ongoing applied research projects include computational materials science, global climate simulations, combustion modeling, transportation, heart modeling, optical computing, and computational nanoscience.

The ORNL Computational Physics and Engineering Division (CPED) offers capabilities in computational physics, computational engineering, integrated computing applications, and nuclear engineering computations and analysis. CPED has a 30-year history of applying computers to physical science problems relating to energy, the environment, and health and safety research.

Additional expertise, distributed throughout ORNL, is applied to scientific challenges as described in Sect. 4.3.2.1. In addition, the Chemical and Analytical Sciences Division is exploring computational chemistry and nanotechnology; the Chemical Technology Division is performing simulations of transport phenomena in chemical processes; and the Physics Division is engaged in computational nuclear structure physics and computational astrophysics. The Joint Institute for Computational Science promotes collaborative relationships between research groups at ORNL, the University of Tennessee (UT), and the UT-Battelle core universities and encourages and facilitates the effective use of high-performance computing resources in the southeastern United States.

These resources are being applied to the development of applications and forefront computing tools that support DOE missions, as outlined in Sects. 4.3.2.1 and 4.3.2.2.

4.3.2.1 • Applications

Climate Prediction

Simulation will be an important tool in reducing uncertainties in climate predictions and determining the social and environmental consequences of changes in energy use, land cover, and population. Future models will close the gap in spatial scales between large-scale circulations in the ocean and the atmosphere and regional climate concerns. Climate modeling an order of magnitude more detailed than existing models is needed to study critical small-length-scale factors. The output of these detailed simulations will make it possible to assess the impacts of climate change on regions such as the eastern or southeastern United States.

ORNL is a major contributor to the process research and modeling efforts that are advancing the understanding of global climate systems. These efforts include the collection and analysis of data needed to assess the potential for and consequences of global warming; ORNL houses three major repositories of data related to global climate change. Its computing and communications resources are used to ensure efficient storage and rapid retrieval of these extensive data sets and to support data mining and pattern analysis. For example, ORNL has developed a low-cost, highly flexible Web-based data distribution system, Mercury, which is being used by a number of agencies in field research projects.

Working with the Argonne National Laboratory and the National Center for Atmospheric Research (NCAR), ORNL has advanced the use of massively parallel computers for climate modeling through the development of numerical methods and parallel algorithms and the implementation of CCM, the NCAR Community Climate Model, on the IBM RS/6000 SP and the SGI Origin 2000. Work to develop new climate models that can take advantage of new levels of supercomputing power continues through DOE's Climate Change Prediction Program.

Researchers in the Energy Division, the Environmental Sciences Division, CPED, and CSMD are working together to establish a regional climate prediction center at ORNL. Plans include coupling general circulation, terrestrial, and regional models and creating an interdivisional computational grid environment.

Materials

Insights gained from simulations of the properties and behavior of materials, which cost less and take less time than laboratory experiments, are accelerating the development of new, technologically advanced materials that can improve the efficiency and economy of energy production and use, contribute to new technologies, and lead to new products. Scientists at ORNL are using massively parallel processors and newly developed computational methods to carry out a variety of projects:

- Accurate simulation of the properties of materials whose behavior depends on the electronic structure of systems comprising hundreds to thousands of atoms. Until recently, such investigations were considered untenable because of the large number of particles necessary for accurate simulations.

- First-principles calculations of variations of electrical resistivity in layered magnetic alloys, which offer the promise of improved magnetic storage systems.
- Simulations of the collisions and transport of energetic ions in crystals. The combination of these simulations with experimental tools at ORNL, such as the Z-contrast scanning transmission electron microscope, affords a unique opportunity to study the complex nature of surfaces and interfaces.
- Analysis of material performance in automotive applications, in an integrated effort that comprises developing detailed vehicle models, modeling lightweight materials (a high priority for automotive applications because they can improve fuel economy), and combining these models to analyze material performance during collisions, providing information that would otherwise have to be obtained from expensive crash testing.

Further advances in computational capability will extend the ability to predict and tailor the properties of materials, supporting the aims of the Advanced Materials Initiative (see Sect. 4.5).

Fusion Energy Sciences

The fusion research community pioneered the use of nationally networked supercomputing, and modeling and simulation continue to be key tools for developing the knowledge base to support the use of fusion as an energy source. Increased computational power is expected to open the way for detailed three-dimensional (3-D) simulations of a wide range of confinement schemes and plasma phenomena.

Researchers in the ORNL Fusion Energy Division (see Sect. 5.1.4), in collaboration with CPED and CSMD, pioneered the application of massively parallel computers and associated programming techniques to fusion calculations. They also participated in the Numerical Tokamak Turbulence Project, performing large-scale calculations of plasma turbulence and anomalous transport on computers at ORNL and at the National Energy Research Scientific Computing Center (NERSC) at the Lawrence Berkeley National Laboratory in an effort to improve predictions of plasma performance.

ORNL is currently pursuing improved models of the edge plasma region. This includes work relevant to the coupling of edge-modeling packages to atomic physics modules such as those developed as part of ORNL's Fusion Program by the Physics Division in collaboration with Auburn University. Work is also under way to extend radio-frequency (rf) plasma heating models developed at ORNL, with the aim of providing a much higher resolution 3-D, full-wave description of rf heating systems, including antenna coupling, wave propagation, and plasma-wave interaction.

Genomics

Computational biology, particularly those applications focusing on genome analyses, requires the routine and recurrent use of a number of codes, many with terascale requirements. These codes are essential for processing and analyzing the massive amounts of data on human gene sequences that are now being generated. High-performance codes—for assembly of hundreds of thousands of "shotgun" sequencing fragments generated per day, for gene recognition and modeling, for assigning the many new genes and proteins to functional families and computing structural folds, and for facilitating large-scale genome sequence comparisons—will be integrated in a coordinated community effort. Developing efforts in structural genomics and computational biotechnology will create a demand for additional computational tools to address detailed molecular structures and even more complex biological systems.

As part of its strong and rapidly growing computational biology and bioinformatics effort (see Sect. 4.2.4), ORNL has developed DNA sequence analysis tools such as GRAIL™ (Genome Recognition and Analysis Internet Link), other genome informatics resources, and protein classification and structure prediction tools that are widely used by the international biology community. New tools and approaches are being created to address a variety of challenges. The focus is on extending the range of understanding of biological phenomena from molecules to systems to phenotype and organism function. This understanding is critical to DOE's science and environmental quality missions.

Biomedical Engineering and Physics

Biomedical engineering and bioengineering (BME) research draws on physics, chemistry, mathematics, and engineering in addressing problems of human health. BME includes bioinformatics, the application of computer science and technology to problems in biology and medicine, from information processing (storage, retrieval, and analysis) to the modeling of biological and behavioral processes.

As described in Sect. 5.1.2, ORNL is engaged in the development of a BME program that comprises efforts in medical telesensors, biosensors, medical diagnostics, and biological systems modeling, all of which present challenges in bioinformatics. The Laboratory is also supporting an effort by DOE, in collaboration with other government agencies, to develop a National Virtual Human Initiative to produce a computationally based environment that condenses and organizes existing information on human anatomy, physiology, genetics, toxicology, and disease. Modeling of human systems and subsystems in an integral fashion will help to extract the full implications of this information in terms of human responses to external and internal stimuli. Computational challenges for this effort include the massive amounts of data involved and the need for dynamic modeling over a wide spectrum of spatial and temporal scales, with highly visual input and output at remote locations. Success in these efforts will require the highest level of computer resources, visualization capability, and collaborative and distributed computational environments.

Combustion

Internal combustion engines have been identified as the source of one-third of the world's pollution and ozone-depleting greenhouse gases. Emerging demands for emission reduction will require the development of dramatically cleaner and more efficient combustion technologies. Detailed computational models can improve the understanding of combustion, leading to innovative designs that achieve lean fuel limits, low emissions, and high efficiency.

ORNL is developing advanced predictive capabilities for combustion processes to support the design of next-generation vehicles and environmentally responsive technologies. Efforts include the implementation of KIVA-3 (a powerful computational fluid dynamics code from the Los Alamos National Laboratory that is widely used in the design and analysis of internal combustion engines) in a parallel processing environment, thus advancing the solution of large-scale combustion problems on scalable systems.

As a member of the Supercomputer Automotive Applications Partnership, an element of the U.S. Council for Automotive Research, ORNL contributed to the development of a "library" of computer models for engine combustion and vehicle airflow challenges common to all automotive designs. ORNL currently has cooperative R&D agreements with the automotive industry to study combustion as it relates to advanced automotive engine design and with the paper industry for improvements in boiler technology.

Combustion modeling must also address the effects of engine and turbine materials on efficiency and pollutant emission. As a world leader in theoretical and experimental materials science, particularly in the fabrication and analysis of new alloys, ORNL will use advanced materials modeling to design more fuel-efficient automotive engines and turbine blades that can be operated at higher temperatures, with greater efficiency. The CSMD and the Engineering Technology Division are working on a Laboratory Directed R&D (LDRD) project to model the catalysis and surface chemistry of catalytic converters in an effort to speed design cycles for these components and improve their ability to remove pollutants from automobile exhaust.

4.3.2.2 • Resource Development

As the development of more powerful supercomputers continues, advances in processing power must be complemented by advances in computing, communications, and information tools and technologies. Fully exploiting the power of massively parallel machines requires the creation of new programming paradigms, languages, scheduling and partitioning techniques, and algorithms, and all of these must be integrated into systems that are accessible and useful to a diverse user community.

For example, a balanced 10-teraflops system requires 5 terabytes of computer memory, 5 petabytes (5×10^{15} bytes) of data storage capacity, and input-output (I/O) capacity exceeding 200 gigabits per second. In addition, operating systems, I/O software, communications software and protocols, visualization systems, data management systems, and network interfaces must all work together with application codes and hardware. Seamless access, secure networks, readily accessible data storage systems, and software and applications must be provided to support user needs.

Hardware

ORNL has demonstrated an outstanding ability to bring large prototype parallel computers to production performance and innovative use, producing results that support DOE missions in science and national security. The Laboratory is now moving ahead to the task of bringing new terascale systems to effective performance through several activities.

- ORNL has acquired and installed a 1-teraflops IBM RS/6000 SP system.
- ORNL has acquired a Compaq AlphaServer SC system, now installed with 400-gigaflops performance capability, with options to upgrade this system to a terascale system in support of the SDAC program or other DOE computing initiatives.
- ORNL has installed a large Linux cluster and is conducting a comprehensive evaluation of cluster interconnects.

Storage Systems

The rapid increase in computing capacity has led to an explosion in the needs of data storage systems. Building on the Laboratory's long history of R&D on new storage systems technology, ORNL researchers, in conjunction with colleagues at the Los Alamos, Sandia, Lawrence Livermore, and Lawrence Berkeley national laboratories and IBM, have developed and deployed HPSS (High Performance Storage System), which is now in use at more than 30 major computing centers throughout the world.

In order to continue its research leadership in storage systems and data access, ORNL has built a distributed storage test bed known as Probe, which connects NERSC and ORNL. Probe is being used to evaluate new storage hardware and software technologies, to improve the performance of storage systems, and to develop new techniques for distributed access to data over the Internet.

Visualization Systems

ORNL has installed a CAVE™ immersive virtual reality environment consisting of a three-walls-plus-floor virtual reality theater powered by a 32-processor SGI Origin computer and a 4-node SGI ONYX2 graphics system linked to the HPSS storage system. The environment provides modelers and researchers with a "virtual, immersive experience" for a wide range of applications currently performed for DOE. A person standing in the CAVE can (1) see projected objects within the observatory and walk around and interact with them; (2) see 3-D stereo images at high video frame rates (exceeding the frame rates of commercial motion pictures); and (3) interact with the virtual displays using a variety of devices, including voice recognition software. The theater can accommodate up to 12 viewers wearing liquid crystal diode (LCD) shutter glasses to view the 3-D stereo projected into the room. Because viewers can still see their hands, bodies, and feet, they need no training to stay oriented in the virtual space.

Networking

Networking is both the infrastructure that ties all other elements of computing together and an area of active research in and of itself. ORNL's history in networking dates from its early connection to MILNET and from its role as an original site on what was first known as MFEnet (the Magnetic Fusion Energy Network), later evolving into ESnet (the Energy Sciences Network). ORNL continued as a main hub on ESnet and was one of the first sites to migrate to ESnet2, as the second-generation network was called when it switched to asynchronous transfer mode (ATM) technology in 1994.

ESnet2 supported groundbreaking experiments in a 1995–97 collaboration between ORNL and Sandia National Laboratories. Researchers conducted multiple-machine linked runs of combustion, climate, and materials codes in one of the first demonstrations of distributed high-performance computing. The two supercomputers at ORNL and Sandia filled and fully used the ATM OC3 connection that linked them. Accomplishments included modifying PVM to handle firewall tunneling for connections between DOE-SC and DOE Office of Defense Programs laboratories, the first low-level ATM cross-country run, and a 1996 R&D 100 award for participation in the development and testing of the GigaNet OC12 interface. ORNL has also been at the forefront of remote operation of laboratory instruments and collaborative technologies through projects such as the Materials Microcharacterization Collaboratory, which gives researchers remote access to scanning tunneling microscopes via a Web-based interface.

As part of the Probe storage test bed, ORNL and NERSC have been selected as the first two sites to be upgraded to DOE's new ESnet3 network. The bandwidth of ORNL's connection to the ESnet will increase from OC3 to OC24. The increased bandwidth will support the implementation of new services such as high-speed file access, videoconferencing, and collaboratories.

ORNL's network research group has been a leader in developing protocols for supporting mobile computing, improving network security, and parallel routing. In addition, ORNL is a silent partner in the Ultrafast Optical Communications Consortium in Atlanta, which links BellSouth, Corning, Nortel Networks, and the Georgia Institute of Technology, which is developing techniques to enhance fiber-optic technology by extending the present-day capacity per wavelength from 10 gigabits per second (Gbps) to 80–90 Gbps.

A workshop on high-performance network research, sponsored by DOE, was held in May 2000 to define a roadmap for establishing a Southeastern High-Performance Network Research Center. The center will address national issues in advanced high-performance networking and its relationship to collaborations and distributed computing. The workshop served to build a consensus and a research plan for leveraging the network expertise and resources in the southeastern United States.

Computer Science and Enabling Technology

ORNL has led the development of several enabling technologies for computer science that have become worldwide *de facto* standards. The PVM (Parallel Virtual Machine) software package is used for distributed computing at tens of thousands of sites. The LAPACK and ScaLAPACK packages for high-performance linear algebra are heavily used in commercial and research software. The QMRPACK package and several sparse matrix solvers developed at ORNL are used in a variety of scientific and engineering applications, ranging from first-principles electronic structure codes for Grand Challenge problems in materials science to codes used in the automotive and aerospace industries.

ORNL initiated the development of MPI, the standard Message-Passing Interface, which simplifies the porting of applications between different parallel machines. Other enabling technologies developed at ORNL include CUMULVS, which supports collaborative remote visualization and steering of distributed applications and fault tolerance for long-running simulations; the Electronic Notebook, in use by hundreds of groups around the world; and HARNESS, an adaptable, heterogeneous computing environment being developed to replace PVM. ORNL is also participating in the specification of a Common Component Architecture (CCA) for high-end computing and developing open source, high-end cluster command and control software.

4.3.3 • ORNL Plans

The DOE-SC theme "Extraordinary Tools for Extraordinary Science" recognizes the importance of mathematical and computational tools in predicting the behavior of complex systems and conducting multidisciplinary research. ORNL expects to build on its present role in developing and applying these tools.

ORNL also proposes to expand its ability to support DOE's missions by accelerating the integration of simulation, modeling, and computation into its R&D programs. The Laboratory proposes to accomplish this by

- establishing a prototype topical computing center that will provide computer capabilities specialized for a small set of key DOE science problems (e.g., materials science and climate);

- purchasing a multiple-teraflops computer in the 2003 time frame and establishing the necessary infrastructure to house this machine, thus maintaining ORNL's lead as the largest DOE-SC computer center;
- continuing its established emphasis on high-end and distributed computing and participation in national initiatives;
- increasing the Laboratory-wide level of expertise in modeling, simulation, numerical methods, and future architecture;
- enhancing the accessibility of its high-end computational power, within ORNL and throughout the research community, by developing the Southeastern Network Research Center in collaboration with the UT-Battelle core universities; and
- establishing a national Digital Earth Observatory by combining the new CAVE and HPSS to provide a virtual earth environment for viewing the massive collection of observed and computed data describing the earth's atmosphere, oceans, surface, and subsurface.

A computer science research program will address the effective use of clustered computers and massively parallel computer systems composed of symmetric multiprocessing (SMP) clusters linked with high-speed network fabrics. Research into numerical methods and programming environments will be aimed at resolving the software issues associated with using these systems in scientific applications. Collaborative technologies will be deployed to enhance and enable interdivisional projects that use high-end computational resources.

This effort will be of direct benefit to a variety of DOE programs. In particular, these actions will support ongoing programs in materials research, computational chemistry, biology, environmental sciences, neutron science, and bioinformatics. The following are key steps to be taken during the planning period:

1. Make the 1.5 teraflops of computational resources of the ORNL Center for Computational Sciences available to researchers funded by DOE-SC (estimated time to completion: 2 months).
2. Develop a prototype topical center to support computational molecular materials research (estimated time to completion: 12 months).
3. Develop one or more enabling technology centers to support the needs of SDAC applications (estimated time to completion: 18 months).
4. Develop significantly more expertise in simulation and modeling, through mechanisms such as encouraging cross-divisional collaborations that make use of simulation centers (estimated time to completion: 18 months).
5. Plan and install advanced networking facilities to increase the internal connectivity at ORNL and to provide a higher level of connectivity with other DOE laboratories and collaborating institutions (estimated time to completion: 24 months).
6. Establish a Southeast Network Research Center involving key universities and institutions in the southeastern United States.

ORNL will draw on its experience in successfully implementing large multiprocessor machines and collaborating with other DOE laboratories and institutions with complementary resources and expertise. Activities will also take advantage of ORNL's ability to assemble interdisciplinary teams of computer scientists, mathematicians, and computational scientists to develop the new algorithms, tools, and software needed to take advantage of increases in computing power.

ORNL will continue to work with universities and other national laboratories on research issues related to collaborative immersive visualization environments. Issues being pursued include handling and viewing of large data sets, use of parallel and distributed computing to drive immersive environments, interactive steering of high-performance computations, access to remote instrumentation in a virtual environment, virtual televisions and recordings, mapping force and tactile feedback, desktop 3-D environments, use of holography, rapid development of synthetic environments from sensor data, human interactions in virtual reality, and computer vision.

Interdisciplinary work will also characterize the development of the prototype topical center. Experience gained in this project will be incorporated into the development of simulation centers. The extension of simulation and modeling capabilities to new areas will be fostered through the encouragement of projects involving multidivision teams (e.g., such projects may receive a higher priority for access to simulation centers).

New tools to support data-intensive computing will be created to manage the large data sets being acquired, for example, to support research in functional genomics and global climate change. ORNL will also continue its work to develop effective tools for visualization and simulation, methods for addressing security issues, and collaborative environments, all in collaboration with other DOE laboratories.

Developments in data storage and network peripherals will be aimed at securing a balanced computational environment consistent with a multiple-teraflops system. The resulting increase in connectivity will strengthen collaborations within ORNL and across the DOE system of laboratories. ORNL will continue as a partner in the multilaboratory HPSS collaboration, which is pursuing further improvements in the flexibility, performance, features, and usability of this software. Expertise gained through the ORNL-Sandia partnership will be applied to the development of networks operating in the range of 200 Gbps.

ORNL will extend its leadership position in distributed storage research by inviting National Science Foundation and Department of Defense supercomputer centers to participate in the Probe storage test bed.

ORNL's network support strategy has two near-term thrusts. First, ORNL has been identified in the ESnet3 procurement as a major hub (along with the Bay Area, Albuquerque, Chicago, and New York). As a result, the bandwidth of ORNL's connection to other DOE laboratories (and to the greater Internet) will increase from OC3 (155 Mbps) to OC24 (1244 Mbps). In anticipation, the local backbone is being upgraded from a collection of shared 100-Mbps Fiber Distributed-Data Interface (FDDI) rings to a hierarchical Switched Gigabit Ethernet lattice. Second, wireless networking will be made available in ORNL's conference rooms and auditoriums. This will enhance the Laboratory's desirability as a venue for conferences and workshops, at which easy access to the Internet is increasingly expected, and will also give participants in meetings access to critical information through their laptop computers.

ORNL will invest a portion of its FY 2001 Laboratory Directed R&D (LDRD) funds (see Sect. 5.7) in the Terascale Computing and Simulation Science Initiative, focusing on four areas: simulation science, high-performance networking, computing system efficiency, and collaboratory software. In September 2000, Secretary of Energy Bill Richardson visited ORNL to announce a five-year plan to modernize the Laboratory's facilities. ORNL's Facilities Modernization Initiative (see Sect. 7.3) includes a new 100,000-ft^2 Computational Sciences Building to house a state-of-the-art computer center facility. Design work for this facility has begun, and it is expected to be ready for occupation in late 2002. In addition, the State of Tennessee has pledged funds to construct a facility to house the Joint Institute for Computational Sciences.

Throughout the planning period, the focus of the initiative will be on the development and integration of skills and facilities for computing, modeling, and simulation and the application of these integrated resources to DOE's needs in science and technology. ORNL will work with DOE to explore opportunities for applying the Laboratory's resources to emerging challenges.

4.4 • Energy and Environmental Systems of the Future

ORNL is developing a comprehensive and systematic approach to meeting the growing global need for energy services. This Energy and Environmental Systems of the Future (E^{2}SF) Initiative addresses the broad challenge, put forward in DOE's mission statement, of fostering "a secure and reliable energy system that is environmentally and economically sustainable."

The United States is well endowed with a variety of energy sources, including substantial fossil fuel reserves, a considerable nuclear power industry, and significant renewable energy resources. Nevertheless, the nation imports about 45% of the petroleum products that it consumes. Moreover, the production and use of energy from fossil fuels are major sources of environmental damage.

The corresponding situation in many parts of the world is far more challenging. Developing countries are experiencing rapid growth in population, energy demand, and the environmental degradation that often results from industrial development. The near-term depletion of energy resources in response to this rapid growth runs counter to the concept of "sustainable development"—development that meets the needs of today without compromising the ability of future generations to meet their own needs.

In 100 years, the world population is projected to be at least 8 billion. Meeting the energy needs of this population will be a formidable challenge. Most forecasters are saying that total world energy services must increase by a factor of 3 to 4 in the next 100 years to meet global needs for energy services and eliminate inequities between more and less developed nations.

It is also increasingly clear that the resources and technology systems meeting a very large proportion of current needs are not sustainable. Not only are fossil fuel sources, especially oil and gas, limited in quantity and nonrenewable; it now appears that the issue of emissions—particularly greenhouse gas emissions—may make the continuing use of fossil fuels nonsustainable even while coal remains plentiful. Increasingly sophisticated models are predicting both global warming and increased variation in climate and weather as a result of energy-related actions. Nonsustainable resource use can also lead to widespread pollution, desertification, deforestation, and species extinction.

The combination of these two elements—increasing needs and nonsustainable resources and systems—requires the identification of ways to increase the availability of energy, safely and affordably, while shifting to significantly different energy paths with minimal effects on human health and the environment. Making this shift will require a thorough understanding of a broad range of science, technology, and policy issues at the interface of energy and the environment.

ORNL is one of the world's premier centers for R&D on energy production, distribution, and use and on the effects of energy technologies and decisions on society and the environment. As a primary performer of environmental science and technology for DOE, ORNL also has extensive resources for understanding and addressing the environmental costs and benefits of energy production and use.

As a result, the Laboratory is uniquely positioned to attack the long-term, large-scale, multidimensional problem of meeting national and global needs for future energy systems (see Table 4.5) that respect human health and the environment. A key aspect of this problem is the issue of carbon management. The risk of global climate change from society's greenhouse gas emissions, of which the most important component is carbon dioxide from combustion of fossil fuels, has triggered efforts to understand the effects of atmospheric carbon dioxide concentrations and develop acceptable options for carbon management.

We are developing a comprehensive carbon management program to explore a range of science and technology opportunities (including policy options) to stabilize atmospheric carbon dioxide concentrations by decreasing the carbon-production potential of the energy system and by reducing carbon dioxide emissions, including the capture and sequestration of atmospheric carbon dioxide and modification of the carbon biogeochemical cycle. This program, which builds on ORNL's broad background in energy efficiency, clean energy, carbon sources and sinks, the global carbon cycle, biomass, and climate modeling, will serve as the cornerstone for the E^2SF Initiative.

Table 4.5
Characteristics of future energy systems

Characteristic	Definition
Clean	Minimal adverse effects on human health and the environment
Efficient	Significantly more efficient than today's energy services
Affordable	No more expensive than today's energy services
Available	Accessible throughout the world
Abundant	Drawing on plentiful resources

Our vision is to become DOE's principal resource for carbon management science and technology. Our goal is to advance the development of the U.S. carbon management agenda through an aggressive and responsive program that identifies and pursues new areas of R&D with significant potential for expanding the nation's carbon management options.

The E^2SF Initiative provides a mechanism for coordinating ORNL's comprehensive activities in energy and environmental science and technology, analysis, and assessment; for defining, selecting, and supporting new activities, with the aim of developing realistic pathways to a sustainable energy future; and for creating and using partnerships to bring together complementary resources in addressing this problem. DOE sponsors for the activities that make up the E^2SF Initiative include DOE-SC, DOE-FE, the Office of Energy Efficiency and Renewable Energy (DOE-EE), and the Office of Nuclear Energy, Science and Technology (see Sects. 5.1 and 5.2). Much of ORNL's work for other sponsors (see Sect. 5.6), such as the Nuclear Regulatory Commission (NRC) and the U.S. Department of Transportation, is also directed toward the solution of energy-related problems. Funding projections for the E^2SF Initiative are under development.

4.4.1 • Approach

The E^2SF Initiative is envisioned as a focused program that comprises

- an integrated R&D approach to the development of future energy systems that respect health and the environment;
- a targeted effort in fundamental science to support improved understanding, assessment, and management of the health, environmental, and economic consequences of energy choices, with particular emphasis on how energy use affects environmental systems; and
- the development and application of R&D capabilities to evaluate technological, environmental, and socioeconomic factors in the development and deployment of systems for the safe, reliable, and efficient generation, storage, and distribution of energy.

Partnerships are a critical element of the E^2SF Initiative. The multidisciplinary nature of the complex problems encompassed by E^2SF presents a number of opportunities for teaming and collaboration, both within the Laboratory and with other organizations that possess complementary capabilities.

4.4.2 • Resources

ORNL has been a leader in R&D at the intersection of energy, environmental, and economic issues throughout its history. The Laboratory's assets include programs in energy efficiency and renewable energy, fission energy, fossil energy, fusion energy, and nuclear energy; programs (e.g., in chemical sciences and technologies, engineering sciences, instrumentation and measurement science, and materials sciences) that address fundamental questions about energy; environmental research programs focusing on global change, environmental processes and systems, the effects of energy development and use, and resource utilization; strengths in environmental management sciences and environmental technology development; and energy-related assessment, policy, and information activities. The strength and breadth of ORNL's capabilities represent an important and defining characteristic of the E^2SF Initiative.

Other ORNL resources are available to support the E^2SF Initiative. The Oak Ridge National Environmental Research Park and unique experimental field facilities in the park support large-scale environmental process research (see Sect. 5.1.2). Facilities such as the Advanced Propulsion Technology Center, the Bioprocessing R&D Center, the Buildings Technology Center, and the High Temperature Materials Laboratory support a broad range of energy-related R&D. Strengths in separations science and chemical processing (see Sect. 5.2.2) represent a notable resource for energy efficiency and pollution prevention. ORNL's computational capabilities are a key asset for studies of energy-related topics, such as climate variability and climate change, combustion, and fusion energy sciences.

The E^2SF Initiative is also linked to the other major Laboratory initiatives. Enhancement of ORNL's neutron science capabilities (see Sect. 4.1) will support investigations of new materials for energy systems, molecular-level studies of environmental chemistry, and analysis of protein structure in support of new means of energy production and evaluations of energy impacts. The E^2SF Initiative draws on ORNL's Complex Biological Systems Initiative (see Sect. 4.2) for information about the biological and environmental impacts of energy choices, for new ways of remediating environmental contamination, and for new resources for clean energy production. Advances in terascale computing and simulation science (see Sect. 4.3) will support more accurate predictions of climate variation and provide insight into energy-related materials and processes. The Advanced Materials Initiative (see Sect. 4.5) will improve the understanding of materials and materials-related phenomena that underpin energy technologies.

Collectively, ORNL's resources make major contributions to meeting the challenges advanced in DOE's energy R&D portfolio: energy security, clean and affordable power, and efficient and productive energy use. The breadth of these resources and their integration of basic research, applied research, and technology development are important assets for the E^2SF Initiative.

4.4.3 • Activities

The near-term focus of the E^2SF Initiative will be on

- understanding the potential for carbon sequestration in terrestrial ecosystems and geologic formations, building on a combination of programmatic support and internal investments, as a first step in delivering the science and technology for understanding carbon sequestration;
- strengthening research and analytical capabilities for evaluating carbon management options through new terrestrial ecosystem facilities and modeling studies;
- expanding our leadership in energy efficiency R&D in the areas of building technologies, distributed energy systems of combined heat and power, and transportation; and
- expanding our clean power R&D in the areas of fuel cells, gas turbines, and reciprocating engines; hydrogen production and storage; methane hydrates; and the genetic basis for agricultural biomass.

These tasks are designed to advance the availability of distributed energy resources for energy efficiency in the near term (now–2010), bioenergy for clean power in the middle term (2010–2020), and fundamental scientific breakthroughs for carbon sequestration and environmental modeling to build the science base for the future (2020 and beyond).

4.4.3.1 • Science and Technology for Carbon Sequestration

The use of carbon sequestration as a major tool for managing carbon emissions depends critically on R&D to understand the carbon cycle and to develop environmentally and economically acceptable options for the capture, transport, conversion, and long-term storage of carbon in the terrestrial biosphere, underground, or in the oceans. In 1999, DOE-SC and DOE-FE sponsored a multilaboratory effort, for which ORNL served as co-leader, to identify key research needs for separating and capturing carbon dioxide from energy systems and sequestering it in the oceans, in geological formations, and in terrestrial ecosystems. The results of this effort, documented in *Carbon Sequestration Research and Development* (DOE/SC/FE-1, U.S. Department of Energy, December 1999), formed the basis for several new research programs within DOE.

The Center for Research on Enhancing Carbon Sequestration in Terrestrial Ecosystems (CSiTE) links the R&D capabilities of ORNL, the Pacific Northwest National Laboratory, the Argonne National Laboratory, and several universities and research institutions. The goal of CSiTE is to discover and characterize links between critical pathways and mechanisms for creating larger, longer-lasting carbon "pools" in terrestrial ecosystems. Research is designed to establish the scientific basis for enhancing carbon capture and long-term sequestration in terrestrial ecosystems by developing:

- a scientific understanding of carbon capture and sequestration mechanisms in terrestrial ecosystems across multiple scales, from the molecular to the landscape,
- conceptual and simulation models for extrapolation of process understanding across spatial and temporal scales,

- estimates of national carbon sequestration potential, and
- assessments of the environmental impacts and economic implications of carbon sequestration.

Sites for field research include the Oak Ridge National Environmental Research Park, building on ORNL capabilities for large-scale environmental process research (see Sect. 5.1.2).

ORNL is also a member of GEO-SEQ, a public-private partnership sponsored by DOE-FE that conducts R&D to deliver information and technologies for the safe and cost-effective geologic sequestration of carbon dioxide. Other partners include the Lawrence Berkeley National Laboratory, the Lawrence Livermore National Laboratory, and the National Energy Technology Laboratory.

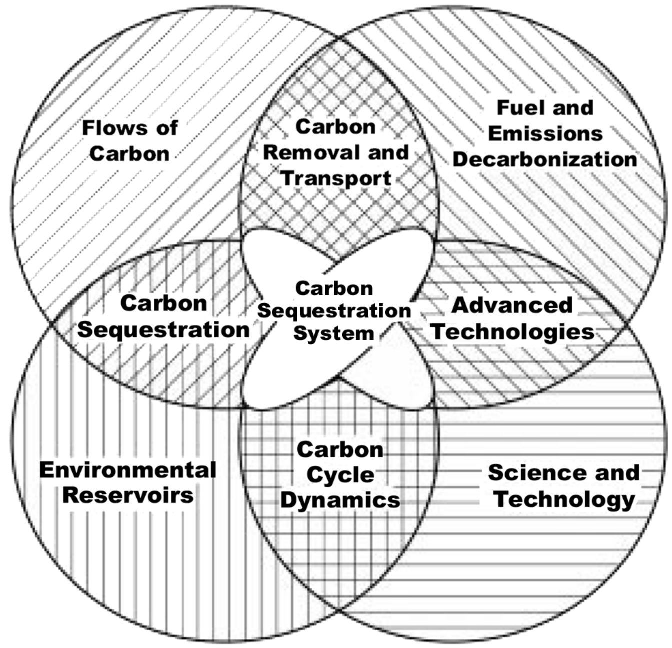

Figure 4.5
Deploying an effective carbon sequestration system will require an integrated program of science, enabling technology, and advanced power systems—all dependent on better understanding of environmental carbon dynamics. *Source:* D. Reichle et al., *Carbon Sequestration Research and Development,* DOE/SC-FE-1, U.S. Department of Energy, December 1999.

A project being conducted by CSiTE for DOE-FE involves R&D to support optimal selection and delivery strategies for maximizing carbon sequestration and reclamation of degraded land using fossil fuel combustion byproducts. In addition, ORNL's Environmental Sciences and Metals and Ceramics divisions are collaborating on a DOE-FE project involving biomineralization for carbon sequestration.

Formation of carbon dioxide hydrates on the deep ocean floor has been proposed as a method of long-term carbon sequestration. This process, as well as the formation of methane hydrates (see Sect. 4.4.3.4), is being studied at ORNL in a one-of-a-kind Seafloor Process Simulator.

These efforts will serve as the nucleus for the development of a broad program to address the scientific and technical needs for carbon sequestration

4.4.3.2 • Analytical Capabilities for Evaluating Carbon Management Options

Evaluating the effectiveness of technologies for carbon sequestration and other means of greenhouse gas reduction will require understanding and capabilities well beyond the scope of current knowledge. Many physical, natural, and socioeconomic interactions of carbon management options are not yet understood. Effective carbon management will require not only an understanding of the environmental, economic, and social trade-offs of technology options to reduce greenhouse gases but also the development of alternative responses to reduce the impacts of higher greenhouse gas concentrations.

ORNL plans to build on and expand its research and analytical capabilities for evaluating carbon management options through new terrestrial ecosystem facilities, drawing on the resources of the Oak Ridge National Environmental Research park, and modeling studies that take advantage of the Laboratory's distinctive strengths in analysis and assessment and its resources for computing and simulation.

Terrestrial Ecosystem Facilities

The DOE-SC Office of Biological and Environmental Research (OBER) has chartered a multi-laboratory and university effort, led by ORNL and the Brookhaven National Laboratory, to develop a science-driven requirements document for the development of large-scale terrestrial ecosystems research facilities. These facilities will be a key resource for understanding the causes and effects of climate variability and climate change, climate prediction, carbon sequestration, and regional climate science and determining appropriate responses.

As described in Sect. 5.1.2, ORNL plans to integrate its expertise in ecosystem research, the carbon cycle, carbon sequestration, environmental sciences, ecological process studies, landscape ecology, and global carbon science with its leading-edge capabilities for measurement, modeling, and monitoring of the environment to define and create new approaches to ecosystem research. Leveraging and enhancing ORNL's current assets in large-scale ecosystem manipulation, integrated data management, ecological modeling, measurement science and sensor development, and computational science will provide DOE with capabilities to improve the understanding of large-scale environmental processes and the response of ecosystems to energy-related stresses.

A critical component of this new thrust will be the ability to address the effects of multiple factors (e.g., temperature and carbon dioxide) and determine the effects of multiple stresses on ecosystems. A better understanding of environmental processes at multiple scales of resolution is critical to addressing the issues associated with carbon management.

Carbon Management Modeling

Tools and techniques are needed for determining the social, economic, environmental, and security consequences of particular choices of energy technologies and selecting the policies that will be most effective in bringing about a sustainable energy future. ORNL has unique resources for developing and applying these tools and techniques. Its expertise in the natural sciences, economics, and social science is applied to environmental impact assessments and to the development of ecological and regional-scale risk analysis, regional and global-scale modeling, uncertainty analysis, and radiological hazard assessments.

ORNL also has unique resources, derived from its strengths in the engineering and energy sciences and technologies, for developing and applying assessment and prediction tools and techniques. Ongoing activities include applied research and integrated assessments of the engineering, environmental, and social impacts of a broad range of energy-related activities, drawing on expertise in the natural, social, and engineering sciences and in technology development.

The need for a comprehensive modeling framework to evaluate carbon management options is being addressed by two Laboratory Directed R&D (LDRD) project involving researchers from six ORNL divisions (Environmental Sciences, Life Sciences, Energy, Engineering Technology, Computational Physics and Engineering, and Computer Sciences and Mathematics). They are developing models that will support cost-benefit analyses of a mix of energy, sequestration, and adaptation technologies, predicting their impacts on atmospheric carbon dioxide levels and assessing alternative policy responses for limiting or reducing carbon dioxide emissions. Natural impacts on carbon dioxide levels (e.g., volcanoes, forest fires, El Niño) will also be taken into account. Terrestrial and ocean sequestration will be compared in terms of cost and the expected carbon storage time. Risks of carbon management strategies will be analyzed, and life cycle analysis and uncertainty analysis will be conducted. The models will update and combine existing global carbon cycle models, energy technology models, and economic models. They will be adapted to use different programming languages across platforms and make complex calculations on parallel supercomputers (e.g., ORNL's IBM SP). Researchers at ORNL and the Pacific Northwest National Laboratory (PNNL) will work together to use PNNL's existing integrated assessment models as a test bed to evaluate carbon management options related to carbon cycle dynamics.

Beginning with this LDRD-funded activity and continuing with future research projects, ORNL expects to play a leading role in the development and application of methods for assessing the costs and benefits of technological and institutional alternatives that will enhance the ability to adapt to climate change and vulnerability.

4.4.3.3 • Energy Efficiency

Improving the efficiency of power generation, transmission, distribution, and use supports carbon management in several ways. If power is used more efficiently, then the amount of power that must be generated is reduced, thus lowering the emissions associated with generation. Improvements in efficiency also make it more economical to use renewable resources. Finally, energy requirements can be reduced through distributed generation—the production of electricity close to the point of use, eliminating losses associated with transmission and distribution and providing opportunities for cogeneration (e.g., combined heat and power).

ORNL's capabilities and expertise are applied to a diversity of tasks in energy efficiency and renewable energy for DOE-EE, as described in Sect. 5.2.1. Strengths in building technologies, distributed energy systems, and transportation are particularly applicable to carbon management. ORNL will work to expand these strengths through the development of new facilities, capabilities, and partnerships. Resources will include a new Building Science Research Facility, the designation of the Power Electronics and Electric Machinery Research Center as a user facility, a growing program in carbon composites research, and partnerships drawing on the capabilities of the National Transportation Research Center.

Two key near-term actions have been identified in this area. First, we will initiate laboratory characterization and field testing of novel systems that integrate power production and space conditioning in buildings. Second, we will identify key R&D needs in transportation by facilitating the development of a technology roadmap for the 21st Century Truck Program.

4.4.3.4 • Clean Power Systems

Atmospheric carbon dioxide emissions can be curbed by using fuels that emit less carbon (e.g., substituting natural gas for coal) or energy technologies that emit no carbon (e.g., electricity from nuclear, hydroelectric, wind, and solar power plants). Renewable energy sources that recycle carbon dioxide, such as biomass feedstocks, offer an array of low-carbon options, including liquid transportation fuels, chemicals, materials, and electricity.

Nuclear energy represents an important element of an integrated clean energy supply strategy, and ORNL's long-term involvement in nuclear technology and safety has provided the Laboratory with distinctive capabilities and facilities for the R&D needed to support this energy option. Current R&D activities (see Sect. 5.2.3) include performing tests aimed at facilitating license extensions for boiling water reactors, developing enabling technology to lower the cost of future generations of nuclear power plants, and basic research on fuels and high-temperature irradiated materials. ORNL is also working to ensure acceptable levels of safety for nuclear power plants.

In the longer term, fusion energy could be an attractive element of the global energy system. As a complement to fission energy, fusion offers potential safety advantages deriving from the low stored energy of fusion power systems, the minimal risk of proliferation, and substantially smaller volumes of radioactive wastes from the fusion fuel cycle. ORNL manages a broadly based fusion energy sciences program (see Sect. 5.1.4), sponsored by DOE-SC's Office of Fusion Energy Sciences, that supports DOE's aim of demonstrating fusion's potential to be an economical, environmentally acceptable energy source.

ORNL will continue its efforts to improve the efficiency of power generation, with an increasing emphasis on improvements in fuel cells, gas turbines, and reciprocating engines, supported by DOE-EE and DOE-FE. Programs in hydrogen production and storage will also be expanded. In addition, the Laboratory is investing in two areas that offer significant potential as new sources of energy: methane hydrate and bioenergy.

Methane Hydrate

Methane hydrate—a crystalline solid consisting of methane molecules surrounded by frozen water molecules—is found in arctic permafrost and deep ocean sediments. It represents a vast primary energy resource and, by some estimates, contains more carbon as methane than all other hydrocarbons combined, including coal. Although methane hydrates have marvelous potential as an energy resource, they also represent a potential risk for global warming should methane, one of the greenhouse gases, be released in large quantities. DOE's Office of Fossil Energy has recently undertaken a methane hydrates research program to evaluate this resource and to determine the potential for production of methane from it in a safe and environmentally appealing manner. The DOE-FE program (see Sect. 5.2.2) focuses on four areas: characterization and evaluation of the resource, climate change implications, seafloor stability and safety, and utilization of the resource (via methane production). The Methane Hydrate Research and Development Act of 2000 (P.L. 106-193) authorizes a five-year, $47 million program on methane hydrates R&D.

Several teams involving ORNL divisions and universities are conducting exploratory research. LDRD funds have been used to construct a Seafloor Process Simulator at ORNL. This unique test facility enables progress in developing and testing observational and sampling technologies; understanding the formation, accumulation, and stability of methane hydrates; and examining the biogeochemical fate and transport of methane and carbon dioxide. Preliminary research into enhanced seismic characterization has been conducted in the Arctic, with another campaign planned in collaboration with Canadian, Japanese, and German researchers. New computational methods to improve algorithms for interpreting geophysical data are being developed in collaboration with the U.S. Geological Survey. A recently initiated project will carry out molecular dynamic simulations that will advance our understanding of hydrate physicochemical properties. These projects form the basis of a comprehensive program that covers the primary research needs and positions ORNL to support DOE in achieving its goals as new research needs emerge.

Bioenergy

ORNL's Bioenergy Feedstock Development Program conducts R&D for both the power sector and the transportation sector, with the aim of developing new energy crops with increased yields, pest and disease resistance, and drought tolerance for conversion to fuels and power.

ORNL is expanding a research partnership with DOE's National Renewable Energy Laboratory (NREL) to improve the use of bioenergy and biologically based product systems through research and integrated analysis. The closer working relationship will assist both laboratories in meeting the needs of DOE's Biofuels and Biomass Power programs, which currently fund crop development research through ORNL and conversion research through NREL. For example, feedstock supply and conversion models will be linked to facilitate systems improvement approaches. This partnership also involves the planning and conduct of several collaborative R&D efforts involving linked plant biosciences and bioprocessing research. Goals include more efficient production of bioenergy and bioproducts and facilitation of the use of basic plant biosciences in enabling advanced technologies for carbon management.

In November 2000, DOE established the National Bioenergy Center to help the United States meet its energy needs, manage its environmental challenges and strengthen economic opportunities in rural America. This virtual center, co-led by ORNL and NREL, will reach into all DOE laboratories and universities to gather the best expertise available and coordinate efforts to support technical improvements in efficient and economical use of biomass in agriculture and forest-based industries. It will also foster efforts such as a joint LDRD project through which ORNL and NREL are working to map the genes that control carbon allocation and partitioning above and below ground, leading to optimized biomass development for (1) product conversion from stems and branches and (2) carbon sequestration with the root system.

4.4.4 • Creating Integrated Solutions

The E^2SF Initiative will build on the activities outlined in Sect. 4.4.3 to create integrated solutions for addressing global energy needs, bringing together "best-in-class" expertise in partnerships that span disciplines and institutions. Most of ORNL's divisions and programs will play key roles in developing E^2SF. In East Tennessee, the National Transportation Research Center links the transportation programs at ORNL and the University of Tennessee (UT), presenting opportunities to develop integrated solutions for management of emissions associated with transportation, and the Joint Institute for Energy and

Environment focuses the resources of ORNL, the Tennessee Valley Authority, and UT on finding solutions to key national and international issues of energy, economics, and the environment. The four DOE laboratories managed by Battelle businesses—ORNL, Brookhaven National Laboratory, Pacific Northwest National Laboratory and the National Renewable Energy Laboratory—are linking their resources in the Battelle-DOE Carbon Management Network. The planned DOE Multilaboratory Regional Climate Network will contribute to the understanding of carbon dynamics.

The development of partnerships to bring together complementary resources will be a hallmark of the E^2SF Initiative as ORNL moves forward, building on the initial focus on carbon management, to develop realistic pathways to a sustainable energy future. The E^2SF Initiative provides a framework and a focus for the Laboratory's support of DOE's general goal for energy resources: "Promote the development and deployment of energy systems and practices that will provide current and future generations with energy that is clean, efficient, reasonably priced, and reliable."

4.5 • Advanced Materials Initiative

A new initiative in advanced materials is aimed at sustaining ORNL's position as a world-class advanced materials R&D laboratory supporting DOE's missions. This initiative includes the development of a recognized capability in nanoscale science, engineering, and technology; the construction of a new Advanced Materials Characterization Laboratory; the development of extraordinary tools for materials characterization; the extension of ORNL's capabilities for synthesis, characterization, and processing of soft materials; and the establishment of a Joint Institute for Advanced Materials.

4.5.1 • Nanoscale Science and Engineering

A key aspect of the Advanced Materials Initiative is the development of a program, supported by an investment of Laboratory Directed R&D (LDRD) funds (see Sect. 5.7), in nanoscale science, engineering, and technology (NSET). This program supports both the National Nanotechnology Initiative (NNI), announced by the White House in January 2000, and the Department's continuing efforts to advance the fundamental understanding of nanoscale phenomena through experiment, theory, and simulation; to develop new methods for predicting these phenomena; and to extend the ability to design, synthesize, and characterize materials at the atomic level, leading to new and enhanced functionality.

Nanoscience is concerned with discovering, understanding, characterizing, and fabricating materials and systems with novel properties, phenomena, and processes that occur primarily because of their small size. Structures having dimensions of 1 to 100 nm (10^{-9} to 10^{-7} m) can induce important property changes that go well beyond those of their isolated component molecules (~1 nm). Additionally, properties induced by such structures may not be predictable from those exhibited by larger structures. New behaviors associated with the nanoscale are not merely the result of orders-of-magnitude reduction in size, but are caused by the emergence of genuinely new phenomena. These include the effects of confinement on electronic structure, the dominance of interfacial and surface phenomena (in contrast to bulk effects) with increasing surface-to-volume ratio, and purely quantum effects. Consequently, modeling and simulation play an important role, complementing experimental discovery, in developing a full and fundamental understanding of these effects.

Nanoengineering and nanotechnology are concerned with developing structures and systems that use and enhance the significantly improved properties of their nanoscale components. By learning how to control feature size and to assemble appropriate "building blocks," it should be possible to enhance the properties of materials and to create functional devices with greatly improved or entirely new functions. This goal, however, requires both discovering the underlying principles and developing the tools needed to apply them systematically.

In recognition of the critical importance of these emerging fields, the NNI was included as a $227 million increase in the President's FY 2001 budget request to Congress. This multiagency initiative will strengthen scientific disciplines and create critical interdisciplinary opportunities. It is expected to lead to breakthroughs in numerous fields, many of them central to DOE's missions, including materials, manufacturing, energy, environmental quality, information technology, and national security.

DOE is one of six agencies participating in the NNI. Its portion of the FY 2001 NNI budget is $36 million, a 62% increase over FY 2000 investments in these areas. The NNI will build on DOE's unique capabilities for visualizing, characterizing, and controlling matter at the nanoscale and on a broad portfolio of R&D already under way at the Department's laboratories. DOE resources include a diverse array of national user facilities, with unique capabilities for investigation of nanoscale materials and processes, and computational facilities to support the modeling and simulation needed in developing a comprehensive understanding of the nanoworld.

For the second consecutive year, NSET has been identified as a target area for ORNL's LDRD funds (see Sect. 5.7). A one-day workshop held on January 20, 2000, presented information about opportunities for NSET-related R&D to about 90 ORNL scientists and engineers. The workshop also provided ORNL leaders with an opportunity to gather ideas and information about resources and activities that support the aims and directions of the NNI. Working groups focused on four topical areas: materials synthesis and characterization, molecular biotechnology as a route to nanotechnology, chemistry and processing, and computing and electronics.

The NSET component of the Advanced Materials Initiative will position ORNL for the science and technology of the future, building on (1) a strong core materials science and engineering program, (2) a variety of capabilities and expertise to synthesize new materials and to process them into nanoscale configurations molecule by molecule, (3) world-class characterization facilities that can "see" new materials configurations at the atomic level and determine their properties, and (4) high-performance computer modeling and simulation capabilities to understand materials properties and predict new configurations.

The Joint Institute for Nanophase Materials Sciences is a proposed national facility for advancing the understanding of nanoscale phenomena in materials. It will leverage the unprecedented opportunity for new research on the structure and dynamics of nanoscale materials systems that will be afforded by the SNS and the upgraded HFIR. The focus will be on interdisciplinary research areas that benefit from access to neutron scattering, including soft materials, interfaces, nanoscale magnetism, and other nanophase systems. Research will provide the foundation for new nanotechnologies based on these materials systems and will optimize the use of the SNS and the upgraded HFIR for nanoscience-related research.

Working through university and industry partnerships, the Joint Institute for Nanophase Materials Sciences will create an environment and provide facilities for rapid progress in interdisciplinary nanoscale science and engineering. It will also provide training for graduate students and postdoctoral associates in interdisciplinary nanoscale science with particular emphasis on nanoscale materials synthesis and characterization, assembly of nanomaterials systems, and fundamental understanding of nanoscale phenomena.

The Joint Institute for Nanophase Materials Sciences will be housed in a new 5,600-m^2 (60,000-ft^2) laboratory/office complex to be constructed adjacent to the SNS and the Joint Institute for Neutron Sciences. This facility will include clean rooms and specialized equipment for nanoscience research that cannot be accommodated in existing space at ORNL. The Joint Institute for Nanophase Materials Sciences responds to the recommendations of *Nanoscale Science, Engineering, and Technology Research Directions,* a 1999 report prepared by members of the Office of Basic Energy Sciences Nanoscience/Nanotechnology Group, and will provide a unique national resource in the nanosciences.

4.5.2 • Advanced Materials Characterization Laboratory

As a leader in the development of techniques and instrumentation for analysis of materials at the atomic level, ORNL has one of the nation's strongest and broadest materials sciences programs. This area is the focus of collaborative research with universities and industries across the United States. Characterization of materials at ORNL user facilities is a major component of many of these collaborations.

Appropriate housing for the Laboratory's advanced analytical electron microscopes, atom probe field ion microscopes, and similar instrumentation is a high priority. This equipment is now scattered across the ORNL campus in buildings that barely meet the manufacturers' requirements for optimum operation. These buildings will not allow ORNL to maintain state-of-the-art instrumentation for the next generation of this equipment.

ORNL proposes to construct an Advanced Materials Characterization Laboratory (AMCL) to address this issue. A new structure with 1,115 m^2 (12,000 ft^2) of space, the AMCL will provide the high-quality environment required to optimize the performance of sophisticated characterization equipment essential for the next generation of advanced materials R&D. It will foster state-of-the-art materials characterization that is essential for understanding materials and materials-related processes and phenomena that underpin energy technologies and industrial endeavors.

Ideally, this facility will house equipment funded by several DOE offices, primarily the Office of Science (DOE-SC) and the Office of Energy Efficiency and Renewable Energy (DOE-EE). Two of ORNL's major user programs—the High Temperature Materials Laboratory, funded by DOE-EE, and the Shared Research Equipment Program, funded by DOE-SC—include a strong emphasis on electron-beam characterization and related techniques. The user base for these facilities includes a strong industrial component, as well as academic users.

Construction of the facility will be guided by the underlying principles of safety, environmental consciousness, and quality engineering, with the necessary environment, safety, health, and quality oversight. The AMCL is included in ORNL's Facilities Modernization Initiative (see Sect. 7.3.3.1) as a General Plant Project (GPP) budget item with a cost of $4.8 million, to be completed in FY 2003. Costs for the initial capital equipment are estimated at $2 million.

4.5.3 • Extraordinary Tools for Materials Characterization

As the complexity of materials and the requirements on their performance have increased, demands for detailed descriptions of the interactions among structure, composition, and properties of materials have soared. Major probes for characterizing materials include neutrons, X rays, and electrons. To answer critical questions about the nature of matter and to develop the advanced materials needed for more efficient energy systems, DOE must maintain cutting-edge characterization tools in each of these areas.

The Spallation Neutron Source (SNS) and the upgrades to the High Flux Isotope Reactor (HFIR) and associated neutron scattering facilities (see Sect. 4.1) will provide the world's best capabilities for probing materials with neutrons. ORNL's investment of LDRD funds in several key areas of neutron science (see Sect. 5.7) is supporting the development of new tools, including novel instrumentation, advanced neutron optics, and data visualization and analysis, for utilizing these capabilities.

The need for advanced X-ray characterization tools is being addressed by the development of beam lines on the Advanced Photon Source (APS) at the Argonne National Laboratory. Microbeam capabilities are extending the understanding of materials phenomena to mesoscale length scales, elucidating key materials problems such as stress-driven grain growth, aging, and materials failure. ORNL is developing a dedicated microbeam facility directed toward 0.1-μm resolution in collaboration with the University of Illinois, the National Institute of Standards and Technology (NIST), and UOP Research Inc. Funding provided through the DOE-SC Office of Basic Energy Sciences is being applied to develop a mesoscale materials program using microbeams at the APS.

Future needs for electron characterization and related techniques will be supported by construction of the AMCL, as described in Sect. 4.5.2, and by continuing efforts to

Figure 4.6
ORNL researcher examining an image obtained using the *Z*-contrast scanning transmission electron microscope, visible in the background.

expand ORNL's resources for high-resolution characterization of the microstructure and microchemistry of materials, with the goal of acquiring the world's highest resolution electron microscopes. Key areas of expertise include

- analytical electron microscopy, including high-resolution imaging, convergent-beam electron diffraction, electron energy-loss spectroscopy (EELS), energy-dispersive X-ray spectroscopy, spectrum imaging, and energy-filtered imaging;
- atomic-resolution scanning transmission electron microscopy (STEM), including *Z*-contrast imaging and atomic-resolution EELS;
- atom probe field-ion microscopy, including atomic-resolution imaging, high-resolution time-of-flight spectroscopy with single-atom sensitivity, and three-dimensional atom probe techniques;
- analytical scanning electron microscopy, including secondary and backscattered electron imaging, energy-dispersive and wavelength-dispersive X-ray microanalysis, and electron backscattered pattern orientation measurements; and
- mechanical properties characterization with submicrometer spatial resolution, including nano-indentation experiments at ambient and elevated temperatures; hardness, modulus, viscoelasticity, creep, scratch, and fracture toughness measurements; and atomic force microscopy.

A new transmission electron microscope, funded by DOE-EE in FY 2000, will contribute to the needed expansion of ORNL's resources.

4.5.4 • Soft Materials

ORNL plans to extend its expertise in the synthesis, characterization, and modeling of soft materials, such as fluids, liquid crystals, polymers, colloids, and emulsions. Soft condensed matter physics has recently emerged as an identifiable subfield of condensed matter physics, in recognition of both the unique properties and the critical importance of these materials, which include the fundamental building blocks of life itself—DNA molecules, cell membranes, and complex fluids such as blood—as well as a variety of materials of industrial importance.

ORNL will build on its current efforts in soft condensed matter physics to extend the understanding of the relationship between the properties of complex fluids and soft condensed matter systems and the molecular structures, spanning atomic to macroscopic length scales, that give rise to them. The SNS (see Sect. 4.1.1) and the new cold source at the HFIR (see Sect. 4.1.2) will extend ORNL's resources in this area, as will the new tools developed through this initiative (see Sect. 4.5.3).

4.5.5 • Joint Institute for Advanced Materials

ORNL is undertaking the development of a Joint Institute for Advanced Materials. This joint institute will bring together university partners and other collaborators to form an intellectual center to advance the materials sciences. Initial focus areas will include nanoscale science and engineering, soft condensed matter, and materials synthesis. Activities will include workshops, seminars, collaborative research programs, and partnerships involving joint faculty and graduate students. A planning workshop with the University of Tennessee (UT) and the six UT-Battelle core universities is being initiated, and a search for a scientific director for the institute will be undertaken.

5 • Program Descriptions and Directions

As a multiprogram national laboratory, the Oak Ridge National Laboratory (ORNL) carries out research and development (R&D) in support of all four major missions of the Department of Energy (DOE): science, energy resources, environmental quality, and national nuclear security. ORNL also undertakes work that supports other DOE functions and work for other sponsors. Through its Laboratory Directed R&D (LDRD) Program, ORNL supports innovative R&D ideas that have no direct programmatic funding but can and do lead to productive new technical directions.

Our commitment to excellence in science and technology, reflected in the Laboratory Agenda (see Sect. 3), includes the delivery of scientific advances and technological innovations in support of DOE's missions through the R&D programs described in this section. Table 5.1 outlines some specific program directions and their connections to DOE mission areas.

Table 5.1
Relevance of ORNL program directions to DOE missions

	DOE mission area			
Activity	Science	Energy Resources	Environmental Quality	National Nuclear Security
Biomedical Engineering and Bioengineering	S	S	S	M
Virtual Human	S		M	S
Large-Scale Environmental Process Research	S	S	S	
Quasi-Omnigeneous Stellarator	S	S		
Nuclear Physics with Radioactive Ion Beams	S			
Building Science Research Facility		S		
Carbon Composites Research for Transportation	M	S		
Separations Science and Chemical Processing	S	S	S	M
Robotics and Intelligent Machines	S	S	S	S

S = Strongly supportive.
M= Moderately supportive.

5.1 • Science

DOE's Office of Science (DOE-SC) is the largest single sponsor of research at ORNL, supporting a broad range of science programs.

5.1.1 • Basic Energy Sciences—KC

The DOE-SC Office of Basic Energy Sciences (BES) supports a broad spectrum of research in the physical sciences at ORNL through its subprograms in materials sciences, chemical sciences, and engineering and geosciences. Major ORNL endeavors supported by BES include the Spallation Neutron

Source (SNS) and the High Flux Isotope Reactor (HFIR) Upgrade, which are discussed in Sect. 4.1. ORNL's new Advanced Materials Initiative (see Sect. 4.5) also draws on BES support.

The BES **Materials Sciences** subprogram supports a comprehensive fundamental materials R&D effort in support of DOE's missions. An integrated, interdisciplinary approach is emphasized, including major research efforts in neutron scattering, synthesis and characterization of advanced materials, high-temperature materials, soft materials, ceramic processing, superconductivity, surfaces and thin films, synchrotron research, electron beam microcharacterization, ion beam and laser processing, and theoretical studies. The program benefits from access to unique, state-of-the-art materials research facilities and from close interactions with materials-related energy technology programs. Major research initiatives comprise the SNS and the neutron scattering upgrades at HFIR (both described in Sect. 4.1) and the Advanced Materials Initiative (see Sect. 4.5), which includes the development of synchrotron beam lines at the Advanced Photon Source at the Argonne National Laboratory.

The Materials Sciences subprogram operates three national user facilities: the HFIR, the Surface Modification and Characterization Research Center (SMAC), and the Shared Research Equipment Program (SHaRE). In addition, through the Oak Ridge Institute for Science and Education (ORISE), BES supports the Oak Ridge Synchrotron Organization for Advanced Research (ORSOAR) for access to the ORNL beam lines on the Advanced Photon Source at Argonne National Laboratory. These facilities provide specialized research capabilities to hundreds of research scientists and graduate students from universities, industry, and government laboratories.

ORNL is a leader in fundamental materials science and in the development of advanced materials, processes, and characterization technologies. New capabilities will extend ORNL's contributions in these areas. The SNS and the HFIR upgrades are addressing a long-term national need for improved neutron science facilities and will provide outstanding opportunities in many fields. The Advanced Materials Initiative will foster the development of new facilities, tools, and capabilities. New research directions include ultrahigh-temperature intermetallics, ceramic surfaces and interfaces, soft condensed matter, and the effects of reduced dimensionality and nanoscale geometries on materials properties.

The Materials Sciences subprogram also advances the understanding of materials and materials-related phenomena that underpin energy technologies. Basic research in materials sciences is integrated with the R&D efforts of DOE's applied programs, especially the materials-related efforts funded by the DOE Office of Energy Efficiency and Renewable Energy, the DOE Office of Fossil Energy, and the fusion energy sciences program in DOE-SC. Key endeavors that benefit from materials R&D include the Industries of the Future initiative and environmental technology development programs.

The BES **Chemical Sciences** subprogram supports the operation of the HFIR/Radiochemical Engineering Development Center (REDC) complex. The HFIR, which provides the highest steady-state flux of thermal neutrons in the world, is used for neutron scattering R&D, the production of isotopes, materials irradiation, and neutron activation analysis. Neutrons from the HFIR are vital to research in the materials sciences, chemical sciences, magnetic fusion, and life sciences programs at ORNL and for external users and collaborators. Each year approximately 400 researchers use its facilities. Activities at the REDC involve the development and use of production processes and product forms for radio-isotopes, predominantly the isotopes of transuranium elements; the production of portable neutron sources using ^{252}Cf for applications in industry, medicine, and national security; and the operation of the Californium User Facility for Neutron Sciences.

The Chemical Sciences subprogram also supports programs in molecular processes, which feature particular strengths in mass spectrometry, properties of high-temperature aqueous electrolyte solutions, separations chemistry and chemical engineering, organic chemistry of energy resources, actinide science, and hydrothermal and isotopic geochemistry. Current research emphases include improving the under-standing of chemical conversions that underpin new or existing concepts for energy utilization and con-version; exploring the chemistry and physics required to conceptualize new analytical methods; using molecular recognition concepts to design selective separations involving solvent extraction; developing a greater understanding of complex phenomena involved in multiphase separations; unraveling the systematics of the solid-state behavior of actinide elements and compounds; relating the thermodynamic properties of aqueous solutions at extreme conditions to molecular structure; developing advanced battery concepts; and quantifying fundamental geochemical processes that control matter and energy transport.

The ORNL portfolio for the Chemical Sciences subprogram also includes a program incorporating experimental and theoretical research in atomic, molecular, and optical sciences. This work is aimed at understanding, and ultimately controlling, matter on the atomic scale through the investigation of the interaction of atomic particles scattering from solid surfaces or penetrating matter. The program studies the basic physical and chemical processes occurring in atomic interactions and seeks the knowledge needed to purposefully manipulate surface/solid properties. Inelastic processes in plasmas, such as electron-atom/ion/molecule or ion-atom/molecule interactions, are studied because of their pervasive occurrence in a huge range of energy-relevant plasmas, such as those used in lighting, magnetic and inertial fusion energy, and technical plasma processing, again with the dual goals of fundamental understanding and robust control of the processes.

These investigations depend on the production of multicharged ions and the application of several highly advanced, unique experimental techniques to control and observe their interactions with other atomic-scale matter (surfaces, solids, photons, electrons, ions, atoms, molecules, and molecular ions), made possible through the resources of the Physics Division's Multicharged Ion Research Facility and the Holifield Radioactive Ion Beam Facility (see Sect. 5.1.5). Intimately coupled with the experimental programs, providing guidance and supporting existing lines of research, theoretical studies are focused on the development of new physical models based on novel mathematical and computational techniques. Together, theory and experiment continue the basic research needed to make new discoveries, support and drive energy-relevant applications, and pursue a pathway to exercising an extended ability to manipulate and control processes and states of atomic-scale matter.

The BES **Engineering and Geosciences** subprogram sponsors the Center for Engineering Systems Advanced Research (CESAR). CESAR's primary mission is to develop, through innovative research, a core of excellence in the area of intelligent systems technology, supporting the needs of DOE and other customers. In particular, CESAR will be a notable resource for DOE's initiative in robotics and intelligent machines (see Sect. 5.3). CESAR is a collaborative research facility providing access to state-of-the-art technology and equipment in a stimulating research environment. Results and technology advances are distributed through publications in the scientific literature, workshops on selected topics, and the development of prototype systems.

5.1.2 • Biological and Environmental Research—KP

The ORNL Biological and Environmental Research (BER) Program, under the sponsorship of the DOE-SC Office of Biological and Environmental Research (OBER), is one of the broadest multidisciplinary life and environmental sciences research programs in the nation. Goals of the ORNL BER Program are to

- understand the response of the environment to global and regional change, environmental stresses, and resource use through study of the interaction of energy-related physical and chemical agents with living organisms and the environment, including their transport, transformations, adverse health effects, and ultimate consequences to humans and the environment;
- determine gene function in human, other mammalian, plant, and microbial systems on a genome-wide scale and perform comparative analyses of genomes;
- advance the understanding of structure-function relationships by examining the structure of proteins and protein complexes and making specialized structural biology tools, including small-angle neutron scattering, mass spectrometry, and computational biology, available to the biological community;
- contribute to the emerging OBER biomedical engineering program in key areas, including biomedical and medical telesensors, efficient laser-based diagnostic and therapeutic procedures, biocompatible materials, novel bioinstrumentation development, and large-scale biomedical systems modeling and simulation;

- contribute to DOE's Nuclear Medicine Program and other beneficial applications through leveraging with advances in molecular biology and other rapidly developing fields;
- develop the scientific understanding for effective bioremediation of metal and radionuclide contamination;
- operate state-of-the-art facilities in functional genomics (the Mouse Genetics Research Facility) and structural biology (the Center for Structural Molecular Biology);
- provide world-class data management and analysis systems for global change and genome research programs; and
- transfer research findings and technological developments to the private sector.

Research in the life sciences addresses the understanding of complex biological systems and includes comparative and functional genomics (involving model systems such as the mouse, microbes, zebrafish, and plants), genetics, biochemistry, biophysics, toxicology and risk analysis, nuclear medicine, biomedical engineering, analytical technologies, and computational biology and bioinformatics. The Laboratory's Complex Biological Systems Initiative, described in Sect. 4.2, is an integrated activity that draws on resources from these and other ORNL programs.

ORNL proposes to integrate its resources to develop a biomedical engineering program in support of the missions of OBER and other federal agencies.

Biomedical Engineering and Bioengineering

Biomedical engineering and bioengineering (BME) research has experienced significant increases in federal funding since 1997. Funding provided to the National Institutes of Health (NIH) in this area has doubled over the last four years and is now nearly $800 million per year.

A focused planning effort at NIH has resulted in the creation of the Bioengineering Consortium (BECON), which includes all NIH institutes and several other federal agencies, such as DOE, the National Science Foundation (NSF), and the Defense Advanced Projects Research Agency (DARPA). Of the $800 million in FY 2000 funding for BME, BECON was directly involved in coordinating about $30 million. The rest of the support was provided by programs at the various NIH institutes and centers. The Office of Biological and Environmental Research (OBER) within DOE's Office of Science is developing a BME program that is expected to grow to $10 million per year in FY 2001. The NSF's BME program is funded at approximately $10 million per year.

BECON has prepared the following working definition: "Bioengineering integrates physical, chemical, or mathematical sciences and engineering principles for the study of biology, medicine, behavior, or health. It advances fundamental concepts, creates knowledge for the molecular to the organ systems levels, and develops innovative biologics, materials, processes, implants, devices, and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health." Given this definition, BME is clearly a key area for DOE's missions in science and energy resources, and it is an area in which ORNL has significant strengths.

ORNL plans to develop a BME program with funding of at least $5 million by FY 2003. The goal is to establish ORNL as a center of excellence for OBER in BME. The expectation is that the program will receive significant funding from NIH and will feature extensive partnerships with medical centers, academic institutions, and industrial partners as appropriate.

The ORNL BME program will establish an integrating focus for a variety of efforts in such areas as medical telesensors, biosensors, medical diagnostics, nanoscience and nanotechnology development, biological systems modeling, and analytical technologies. Many of these are being pursued in or led from the ORNL Life Sciences Division. Other divisions, including the Chemical Technology, Instrumentation and Controls, and Metals and Ceramics divisions, have ongoing efforts and strong interest in this area of research. A BME focus group, chartered in December 1999, includes researchers from across the Laboratory.

ORNL researchers also secured, through rigorous peer review, 3 of the 17 BME pilot projects first funded by OBER in FY 1999. These projects are addressing

- high-throughput hybridization mass spectrometry for disease screening,
- integration of microchannel glass and photosynthetic structures into photoelectrode array implants, aimed at the development of a retinal prosthesis, and
- an advanced synchronous luminescence system for diagnosis of cancer and dysplasia.

ORNL's efforts in BME-related R&D have a strong reputation, with a long history of excellence in analytical chemistry and instrumentation development, including many R&D 100 awards, award-winning publications, citations, community adoption and use of tools developed, impact of clinical applications, and high-quality collaborations with medical centers, academic laboratories, and industrial partners.

ORNL expects to play a key role in supporting OBER's plans in BME, with activities spanning biomaterials and biomechanics; biological, chemical, and genetic sensors; clinical measurements; imaging; informatics and mathematical modeling (see Sect. 4.2.4); biomedical applications of lasers; and therapy. The program will also draw on NIH support, which will be a key element in attaining both the funding level and the scope envisioned for a successful program. The four focus areas of the NIH program—imaging, nanotechnology, tissue engineering (biomaterials), and informatics—cover a broad spectrum of research aligned with work in progress at ORNL. Principal investigators at ORNL have responded to an NIH program announcement for Bioengineering Research Partnerships and will continue to pursue this and other avenues for funding.

Figure 5.1
ORNL's multifunctional biochip provides rapid screening and identification of biological systems and should speed medical diagnosis. It was the winner of a 1999 R&D 100 award.

To ensure success in this effort, ORNL will establish clear scientific goals, develop strong strategic partnerships with academic centers of excellence and with medical centers, and produce a program development plan that sets priorities and includes appropriate resources for proposal development.

ORNL is also developing a human simulation environment that supports the missions of OBER, other DOE programs, and other federal agencies. This effort will be linked to the Terascale Computing and Simulation Science Initiative described in Sect. 4.3.

Virtual Human

A resource to support the modeling and simulation of human biology, the Virtual Human, is under development at ORNL. The Virtual Human builds on the imagery data from the Visible Human Project sponsored by the National Library of Medicine (NLM), which has as its objective the creation of complete, anatomically detailed, three-dimensional (3-D) representations of male and female human bodies.

The goal of the Virtual Human project is to develop a research, teaching, and applications environment in which complex human responses to biological, chemical, and physical stimuli can be predicted and studied. The Virtual Human environment will comprise an integrated suite of models of the human body and its functions within an anatomical framework, which can be adjusted to represent different ages, genders, and physiological and psychological states.

This problem-solving environment will be able to simulate the body's responses to a variety of input stimuli, including trauma (e.g., from a car crash), exposure to chemicals or radiation, and other "insults." Requirements include detailed anatomical models, a wide variety of evaluated data (e.g., physiological, biochemical, bioelectrical, and biomechanical), advanced computational algorithms, and appropriate user interfaces that will allow researchers to invoke many types of simulations and obtain results in a variety of formats, including advanced visualizations and numerical data. Terascale computing resources and petabyte storage capabilities will be required to support the computational needs of the Virtual Human.

A number of organizations have expressed interest in human response modeling, but to date there has been little or no coordination of efforts toward a resource supporting basic science and applications of human simulation. Some of these organizations are working on models for individual organs, while others focus on anatomical models. Work on ergonomics and animation is also under way.

ORNL researchers are presently engaged in the design and implementation of a prototype Virtual Human environment, supported by Laboratory Directed R&D (LDRD) funds. Once the initial Virtual Human resource is established, DOE, the Department of Defense (DOD), the Department of Health and Human Services (DHHS), and the Department of Transportation (DOT) are expected to be its prime Federal agency users. As capabilities are demonstrated, sizable private sector participation is anticipated.

The technical scope and multidisciplinary nature of this effort present a number of opportunities for teaming and collaboration, and ORNL has actively sought partners to contribute to the development of the Virtual Human environment. Collaborations have been established with Penn State and Brooks Air Force Research Laboratory and are about to begin with Boston University, East Tennessee State University, the University of Tennessee, and Vanderbilt University.

ORNL is working to establish formal relationships with the Physiome Project at the University of Washington, which is aimed at developing a common approach to organ modeling; the Center for Human Simulation at the University of Colorado, which is building a number of anatomically based organ or body-region simulations from the Visible Human data; and the BioNOME Resource, a Web-based repository of biocomputational models at the San Diego Supercomputer Center. Opportunities for collaboration with private and nonprofit R&D entities are also being explored.

Work is also under way to explore DOE contributions to an interagency effort to establish a National Virtual Human Initiative. Such an initiative, bringing together the resources of the national laboratories, universities, and other research institutions, would build on DOE's history of involvement in human health issues and address mission needs for information about the health effects of legacy environmental wastes, future energy technologies, and chemical and biological weapons.

Interest in the Virtual Human has been expressed by the DHHS (through the NLM, the National Cancer Institute, and the National Institute of Environmental Health Sciences), DOD, the Federal Bureau of Investigation, and the DOT National Highway Traffic Safety Administration.

Environmental science research covers biogeochemistry, environmental biotechnology, environmental chemistry, ecosystem studies, geosciences, hydrology, microbiology, and environmental assessment. Through the Energy and Environmental Systems of the Future Initiative (see Sect. 4.4), these capabilities will be applied to the development of a deeper understanding of large-scale environmental processes and global climate change and to strategies for carbon management and sequestration.

ORNL plays a key role in environmental data systems for DOE's research. The Atmospheric Radiation Measurement (ARM) Program sponsors the data archive that stores the massive quantities of data collected as part of this multiyear global change research observation project; the archive also provides the general scientific community with ready access to the data. The Carbon Dioxide Information Analysis Center, sponsored by OBER, is acknowledged as one of the world's principal repositories for data and is the focal point for the compilation and dissemination of numerous critical databases, including national fossil-fuel CO_2 emission time series and the Mauna Loa atmospheric CO_2 concentration record. The National Academy of Sciences has designated ORNL as the World Data

Center–A for Atmospheric Trace Gases, and ORNL has provided data in support of international environmental treaties for many years. ORNL also provides data management support to the AmeriFlux network.

Major field-scale research efforts include the Free Air CO_2 Enrichment (FACE) experiment, the Throughfall Displacement Experiment (TDE), and the Center for Research on Carbon Sequestration in Terrestrial Ecosystems (CSiTE), a distributed research center funded by OBER that links ORNL, Pacific Northwest National Laboratory, and Argonne National Laboratory with collaborators from several universities and other research institutions. ORNL is exploring opportunities to expand its involvement in the AmeriFlux program to include field measurement aspects of this activity and modeling of AmeriFlux data to landscape applications. Collaborations with the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) will be pursued.

ORNL is also expanding research that focuses on harnessing microbial processes to remediate radionuclide and metals contamination in the subsurface in support of OBER's Natural and Accelerated Bioremediation Research Program (NABIR). OBER's first NABIR Field Research Center (FRC) has been established on the Oak Ridge Reservation, in the Bear Creek Valley near the Y-12 National Security Complex.

The FRC, which comprises a 100-hectare (243-acre) contaminated area and a 164-hectare (404-acre) uncontaminated area, will be used for long-term field studies to advance the understanding of microbial interactions with groundwater and soil and mechanisms of contaminant degradation and containment. ORNL will operate the FRC for OBER, carrying out hydraulic testing, tracer testing, groundwater and sediment sampling, and other characterization activities. The results of these initial tasks will be used in identifying areas for field studies to be conducted by scientists from DOE laboratories (including ORNL) and universities during the next 5 to 10 years. Researchers will use the FRC to develop an understanding of the complex factors affecting bioremediation and innovative means of enhancing the reactions of microbes with radionuclides, metals, and other contaminants.

ORNL's research on the microbial genome (see Sect. 4.2.3) emphasizes organisms important to global change, carbon sequestration, marine biotechnology, and bioremediation. The NABIR FRC is expected to be a valuable resource for this research. It will also generate data that can be incorporated into the mathematically based numerical models that are an important tool in predicting and planning groundwater management programs and remediation strategies, and it will provide opportunities for comparing computational predictions of bioremediation techniques with actual outcomes.

ORNL proposes to expand its programs in large-scale environmental process research as a means of developing new scientific approaches and facilities to understand the impacts of energy development and use on the environment and creating innovative solutions to major environmental issues.

Large-Scale Environmental Process Research

Environmental processes are active and variable at temporal scales from nanoseconds to millennia and at spatial scales from single molecules to the globe. In examining how complex environmental systems respond to energy use, researchers must base their interpretations and assessments on a sound understanding of these processes.

An enhanced program of research is needed to improve the experimental capabilities of ORNL environmental scientists as they seek to better understand large-scale (regional, continental, global) terrestrial environmental processes. This improved understanding will aid researchers in quantifying how the environment works and in addressing such challenges as sustainably managing resources, adapting to climate change, and predicting the impacts of changes in air, water, or soil quality.

Process studies reveal how natural systems function and are critical to understanding the dynamics and response of ecosystems in a changing environment. Environmental processes, however, are typically studied in isolation. Rarely have interactions between these processes, or between processes and the many stressors that influence them, been studied or quantitatively characterized at the ecosystem scale. The prediction of an outcome that results from several interacting factors (e.g., tropospheric ozone, global warming, changing precipitation patterns, elevated carbon dioxide, and high nitrogen or trace metal loading) is a major challenge in environmental science today.

Another complication is introduced by the fact that, for example, mature forests do not respond to changes in the environment in the same manner as collections of seedlings or small trees (as demonstrated through ORNL research). Modeling approaches for extrapolating from small-scale experiments to ecosystem, landscape, or regional scales must be verified and validated through *in situ* experimental manipulation of larger scale environments.

ORNL researchers have pioneered advances in methodology and approaches to the study of events that define physical, chemical, or biological change in the environment. They have also established approaches to studying natural ecosystems on a large scale, making use of the extensive resources for long-term environmental process research afforded by the Oak Ridge Reservation, a substantial portion [~8,100 hectares (~20,000 acres)] of which has been designated as the Oak Ridge National Environmental Research Park, a DOE user facility.

ORNL plans to integrate this combination of resources and expertise with its leading-edge capabilities for measurement, modeling, and monitoring of the environment to define and create new approaches to ecosystem process research. Leveraging and enhancing current assets in large-scale ecosystem manipulation, integrated data management, ecological modeling, measurement science and sensor development, and computational science will contribute directly to Office of Biological and Environmental Research (OBER) plans, outlined in the Facilities Roadmap Initiative, for integrated user facilities for experimental field research. This activity also supports DOE's science goal and addresses the DOE-SC theme "Protecting Our Living Planet," with specific application to critical questions about energy by-products and climate change, and it is closely linked to ORNL's Energy and Environmental Systems of the Future Initiative (see Sect. 4.4).

Simulation is an important tool for predicting an outcome that results from several interacting factors. Computer models provide both a concise description and a formal integration of information and understanding obtained through environmental process research, as well as a means for projecting ecosystem response into the future under changing environmental conditions. Applying these environmental process models in all their mechanistic detail to simulate long-term responses at large spatial scales requires the use of parallel and other high-performance computing. Building on a long history of environmental modeling at ORNL, the Environmental Sciences Division is working to develop and promote computational environmental science, with the aim of bringing computational science and high-performance computing technology, both software and hardware, to bear on understanding large-scale environmental process.

The well-developed DOE and ORNL investments in scientific infrastructure at the Oak Ridge National Environmental Research Park represent a concentration of resources that is unique among U.S. ecological research centers. The park is home to two major large-scale ecosystem manipulation experiments: the Free Air Carbon Dioxide Enrichment facility and the Throughfall Displacement Experiment. Both are aimed at understanding the impacts of atmospheric and climatic change. The park—particularly the Walker Branch Watershed area—is one of the nation's most intensively studied sites for understanding biogeochemical cycling in a forested

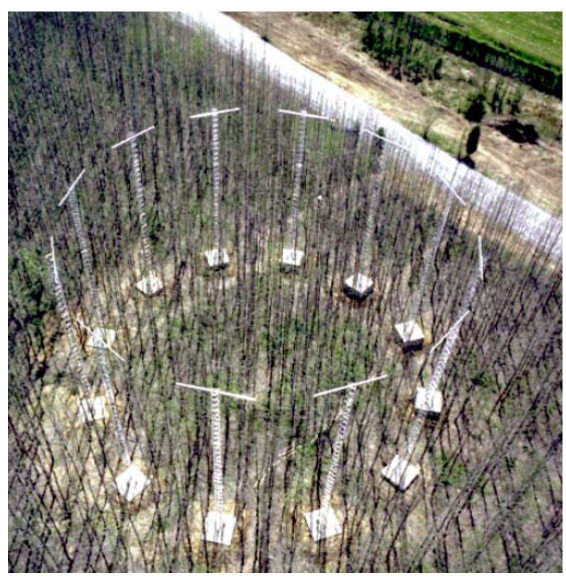

Figure 5.2
The Free Air Carbon Dioxide Enrichment (FACE) facility.

ecosystem. Overall, the park provides a combination of heterogeneous and well-characterized geology and hydrology, ecological diversity, fundamental ecosystem process research, modeling, a long-term data record, historical records of land use change, and dynamic pressures on ecosystems resulting from its suburban/industrial setting. The physiography of this Ridge and Valley setting provides a unique opportunity for several "replicate" catchments on contrasting soil types, further contributing to the value of the site for large-scale experiments.

This activity will enhance the role of the Oak Ridge National Environmental Research Park as a national user facility for research on large-scale environmental processes. It will provide opportunities to build on existing capabilities through partnerships with other national laboratories, other federal agencies, and universities, allowing DOE to maximize the cost-effectiveness of the federal investment in this infrastructure.

Innovations in measurement science and technology will be applied to large-scale ecosystem manipulations to speed the development of the next generation of sensors and environmental monitoring instrumentation and the application of new nuclear and radiochemical tracer and biomarker techniques. Development of advanced methods for measurement of environmental processes will lead to expanded opportunities for cooperative R&D agreements and other forms of partnership with the environmental monitoring industry. ORNL strengths in information and data management will support the transfer of data from on-line sensors to other institutions worldwide through the Internet, making the facilities similar in concept to a "virtual laboratory."

This activity will integrate focused interdisciplinary process research with other experimental, observational, and modeling studies related to ecosystem function and response. It directly supports OBER plans for integrated user facilities for experimental field research, and it is aligned with the findings of a review of the research needed to support an improved understanding of the impacts of global change on forest ecosystems, conducted at OBER's request and documented in *Terrestrial Ecosystem Responses to Global Change: A Research Strategy* (ORNL/TM-1998/27, September 1998). This report calls for a fundamental shift in the scale and integration of ecosystem research: from the current small-scale, single- or two-factor experiments in simple natural or artificial ecosystems to highly coordinated, large-scale, replicated experiments in complicated ecosystems, with many interacting factors evaluated at two or more levels of spatial scale and process resolution. Such experiments will require an unprecedented long-term funding commitment and large-scale experimental research at a few critical sites.

As a follow-on to this report, OBER has asked ORNL and Brookhaven National Laboratory to lead a comprehensive study to identify the key scientific research questions regarding terrestrial ecosystems and the types of new facilities required to address these questions. The study team will include nine national laboratories and a number of universities. The study will complement a similar study being conducted by DOE's Biological and Environmental Research Advisory Committee at the request of OBER.

Table 5.2 presents preliminary funding projections. (The cost of constructing new facilities has not yet been determined and is not included.) OBER is the core sponsor of this activity; complementary funding is being sought from programs within DOE's Office of Energy Efficiency and Renewable Energy (DOE-EE) and Office of Environmental Management and through new partnerships with other federal agency sponsors, including the U.S. Forest

Table 5.2
Funding projections for large-scale environmental process research by fiscal year[a]
($ in millions—BA)

	2001	2002	2003	2004	2005
Operating	4.0	5.0	6.0	8.0	12.0
Capital	0.5	0.5	1.0	1.0	1.0
Total	**4.5**	**5.5**	**7.0**	**9.0**	**13.0**

[a]Construction funding will be required beginning in FY 2002; estimates will be developed in FY 2001.

Service, the Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration, and the Tennessee Valley Authority.

Enhanced university interactions are being fostered through the use of the unique facilities that are part of the Oak Ridge National Environmental Research Park user facility. For example, university investigators have secured independent funding to conduct research in conjunction with the Oak Ridge large-scale environmental process experiments. University and federal agency interactions are also being developed through participation in a university-based multiagency Cooperative Ecosystem Study Unit involving the University of Tennessee, the U.S. Forest Service, the U.S. Geological Survey, the U.S. Park Service, DOE, and seven other (nonagency) partners. Current interactions with the DOE-EE Industries of the Future program may be expanded through field demonstration projects related to forest products industry interests in short-rotation woody crops.

Four user facilities contribute to the ORNL BER Program: the Center for Structural Molecular Biology, the Mouse Genetics Research Facility, the Oak Ridge National Environmental Research Park, and the Bioprocessing Research Facility. The ORNL Center for Global Environmental Studies integrates the Laboratory's science and technology to broaden the understanding of environmental processes and support sustainable development.

5.1.3 • Advanced Scientific Computing Research—KJ

The DOE-SC Office of Advanced Scientific Computing Research (ASCR) supports ORNL research in and application of mathematical, computational, computer, and communications sciences. This includes operating the high-performance computers at ORNL and conducting basic research through the Applied Mathematical Sciences (AMS) subprogram. The Terascale Computing and Simulation Science Initiative described in Sect. 4.3 will extend ORNL's computational resources and expertise to support DOE's missions.

The AMS subprogram supports research in parallel processing algorithms; tools to facilitate the use of parallel and distributed computing systems; and development of applied mathematical, statistical, and computational methods for use in areas requiring high-end computing, such as solid and fluid dynamics, climate dynamics, and biophysics. ORNL is participating in the DOE2000 initiative to create and apply new computational tools and libraries for "national collaboratories" and advanced computational testing and simulation (ACTS). Activities include the Materials Microcharacterization Collaboratory (MMC); the ACTS Scientific Template Library; the Electronic Notebook project; and the Collaborative Management Environment project.

Through the MMC, resources at ORNL, the Argonne and Lawrence Berkeley national laboratories, the National Institute of Standards and Technology (NIST), and the University of Illinois at Urbana-Champaign are available to a wide user community through electronic collaboration. The MMC is supported by ASCR, BES, DOE's Office of Energy Efficiency and Renewable Energy, NIST, and industry.

ORNL's Collaborative Technologies Research Center performs fundamental and applied research in intelligent software agents, information integration, and software engineering. It will play a role in ORNL's commitment to develop and integrate skills and facilities for computing, modeling, and simulation, as will the creation of a human simulation environment, the Virtual Human, described in Sect. 5.1.2.

ASCR also supports innovative, high-risk research that does not fall under the auspices of other DOE programs. The Laboratory Technology Research (LTR) Program supports research that integrates basic and applied disciplines to promote substantial changes in technologies of strategic importance to DOE's missions and to American industry. Activities include cooperative R&D agreements and collaborations with other national laboratories. The LTR program supported 12 projects at ORNL in FY 1999, ranging from basic research on materials properties to the development of improved air conditioning systems.

5.1.4 • Fusion Energy Sciences—AT

ORNL's Fusion Program is a strong and vital component of both the U.S. fusion program and the international fusion community. ORNL staff members conduct experimental research on toroidal confinement of high-temperature plasmas on several large tokamaks and stellarators in the United States and other countries. Theoretical research on high-temperature plasmas uses state-of-the-art computing methods (see Sect. 4.3.2.1) to address transport phenomena, magnetohydrodynamics (MHD) behavior, radio-frequency (rf) heating and current drive, and plasma edge effects. ORNL researchers also develop rf heating and current drive technology and high-speed, frozen pellet fueling technology for fusion research; apply technology in nonfusion areas and transfer technology to the private sector; and contribute to the development of advanced superconducting magnets for fusion and other applications. ORNL is a major contributor to the development of low-activation, radiation-resistant materials for fusion; studies atomic collisions relevant to fusion processes and plasma diagnostics and provides numerical data on atomic and molecular processes relevant to fusion R&D; develops laser-based alpha particle diagnostics; and conducts a variety of R&D projects applying fusion-related technologies and expertise to other fields such as plasma processing and waste disposal.

ORNL's expertise is well matched to the increased emphasis being placed on innovative confinement concepts by the U.S. fusion program. The U.S. spherical torus program, which originated at ORNL, is now centered on the National Spherical Torus Experiment (NSTX) at the Princeton Plasma Physics Laboratory (PPPL). ORNL is a major participant in the NSTX physics program.

ORNL is also deeply involved in the growing national stellarator program. Two approaches—quasi-axisymmetry (QA) and quasi-omnigeneity (QO)—hold promise for the development of compact stellarators. ORNL is partnering with PPPL to propose the National Compact Stellarator Experiment at PPPL, which would test the QA approach, and is working with PPPL and the University of Texas to propose a complementary facility, the Quasi-Omnigeneous Stellarator, to be built at ORNL.

Quasi-Omnigeneous Stellarator

Two promising transport optimization strategies for a compact stellarator fusion power plant concept are being investigated: quasi-axisymmetry (QA) and quasi-omnigeneity (QO). In assessments by the stellarator community, both concepts have been judged to have sufficient promise and to be developed enough for a proof-of-principle (PoP) test.

The National Compact Stellarator Experiment (NCSX), now under development in an effort led by the Princeton Plasma Physics Laboratory (PPPL) and ORNL, would provide a PoP-level test of the QA concept. A complementary QO facility at the concept exploration level is needed to broaden the scientific base provided by the QA PoP test and the Helically Symmetric Experiment (HSX) at the University of Wisconsin to include low-aspect-ratio, non-symmetric stellarator configurations.

ORNL's Quasi-Omnigeneous Stellarator (QOS) is designed to meet this need. The QOS would extend the QO-like optimization of the Wendelstein 7-X (W7-X) stellarator at a lower aspect ratio (reduced by a factor of 3) using a somewhat different magnetic configuration with a small bootstrap current (self-generated by the plasma). The combination of NCSX and QOS, in conjunction with the large, currentless stellarators that have larger aspect ratios—the Large Helical

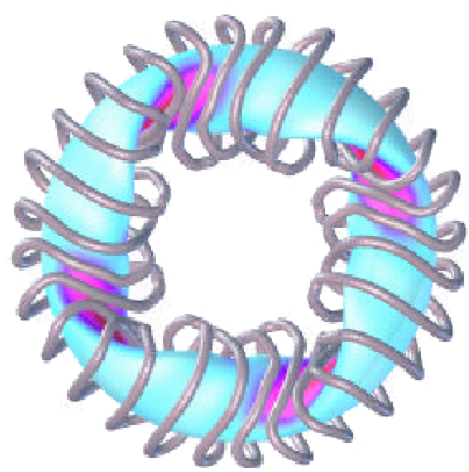

Figure 5.3
The last closed vacuum flux surface and the coils that produce it for a four-field-period QOS configuration.

Device (LHD) in Japan and W7-X in Germany—would provide the database needed for a decision on proceeding to the next step in the world stellarator program.

The major radius and magnetic field for QOS were chosen to limit the total project cost to $8 million (in FY 1999 dollars). This includes design and construction of the QOS and installation of 600-kW electron cyclotron heating (ECH) and a base set of diagnostics.

Three to four years would be required for construction and commissioning of the experiment. Significant resources at ORNL, PPPL, and the University of Texas can be applied to the experiment to reduce costs; these include heating systems, power supplies, control systems, standard tokamak diagnostics, and specialized diagnostics (heavy ion beam probe, phase contrast imaging, etc.), some of which would be available through collaborations with other institutions.

The experimental program would address improvement of neoclassical and anomalous confinement, insensitivity of the magnetic configuration to changes in plasma pressure, reduction and control of the bootstrap current, and use of external coils rather than a plasma current to create most of the confining poloidal magnetic field. Extensive collaborations, nationally and internationally, and participation by graduate students would extend the scope of the program. The QOS experiment would require an annual operating budget of about $4 million.

The ORNL Fusion Program is also applying its strengths in collaboration and strategic alliances to the Virtual Laboratory for Technology (VLT), established by the DOE-SC Office of Fusion Energy Sciences to unify and coordinate the U.S. effort to meet emerging needs in fusion technology. The VLT links the geographically distributed experimental, computational, and information resources of the fusion community, drawing on high-performance research tools that allow scientists and engineers across the country to work together in new ways. Leadership is provided by ORNL, Lawrence Livermore National Laboratory, the University of California at Los Angeles, and the University of California at San Diego.

5.1.5 • Nuclear Physics—KB

The ORNL Nuclear Physics Program emphasizes basic nuclear physics research, both experimental and theoretical, and operates the Holifield Radioactive Ion Beam Facility (HRIBF) and the Oak Ridge Electron Linear Accelerator (ORELA) for nuclear structure physics and nuclear astrophysics.

At higher energies, ORNL has a leadership role on PHENIX, one of the two major experiments at the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory, and is exploring involvement in the ALICE experiment under development at the European Laboratory for Particle Physics (CERN) in Geneva.

Efforts in radioactive ion beam (RIB) physics draw on the capabilities of the HRIBF, which is the only U.S. facility that can produce and accelerate high-intensity, low-energy, tandem-quality beams of radioactive nuclei. The nuclear structure program on the HRIBF will extend the studies of nuclear properties to exotic nuclei not now accessible with stable beams. The nuclear astrophysics program will use RIBs to make pioneering advances in the understanding of stellar explosions.

A theoretical nuclear physics program provides support to both the nuclear astrophysics and nuclear structure programs. Research in nuclear structure theory takes advantage of the opportunities presented by the joint ORNL–University of Tennessee nuclear structure theory program.

The ORELA is a unique, intense pulsed-neutron-source accelerator facility for reaction measurements by time-of-flight neutron spectrometry. The ORELA program is directed toward basic research in nuclear astrophysics and fundamental interactions. Measurements made on ORELA also support DOE's Nuclear Criticality Safety Program (see Sect. 5.4).

Laboratory Directed R&D (LDRD) funds have been used to study the feasibility of using ORELA to test the performance of actinide targets designed for use in high-power beams (e.g., at an advanced RIB facility) and to explore the use of ORELA for production of radioactive species from the electron-induced fission of actinide targets. The results were very encouraging and provide a basis for exploring the development of a high-power target test facility and a production facility for neutron-rich RIBs.

To broaden the understanding of nuclear structure, nuclear astrophysics, and nuclei subjected to extreme temperatures, rotational frequencies, and pressures, ORNL proposes to continue and expand its support of DOE and national needs for nuclear physics with RIBs.

Nuclear Physics with Radioactive Ion Beams

Radioactive ion beams (RIBs) afford a range of scientific opportunities, including the ability to study such topics as

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

The Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL, an isotope separator on-line (ISOL) facility for the production of accelerated beams of radioactive isotopes, is the first U.S. RIB facility devoted to low-energy nuclear structure and nuclear astrophysics research. Radioactive ions are produced when intense beams accelerated by the Oak Ridge Isochronous Cyclotron (ORIC) are directed onto thick, refractory targets. The radioactive elements diffuse out of the target, are ionized, and are mass selected for injection into the 25-MV tandem accelerator, producing beams of 0.1–10 MeV per nucleon for light nuclei and up to 5 MeV per nucleon for mass 80. These beams are ideal for research in nuclear astrophysics and nuclear structure.

An advanced ISOL facility for the production of accelerated beams of radioactive isotopes was identified in the 1996 Long-Range Plan for U.S. Nuclear Science, prepared by the DOE/National Science Foundation (NSF) Nuclear Science Advisory Committee (NSAC), as the next major facility to be constructed for U.S. nuclear science. This facility would provide the larger variety of more intense RIBs needed to take full advantage of the opportunities in this new interdisciplinary research field.

The DOE Nuclear Physics Program is now considering the design and construction of a rare-isotope accelerator (RIA) facility based on a highly flexible superconducting linear accelerator (linac) driver, with the capability for fast in-flight separated beams of rare isotopes. The projected cost of the RIA facility, assuming the start of construction in FY 2002, is about $500 million, with operation beginning in FY 2007.

At the request of the DOE Nuclear Physics Program, ORNL has examined ways of upgrading the HRIBF that would enhance the competitive position of RIB research in the United States until the new facility can be completed. A number of upgrades, with costs ranging from $1 million to $30 million, have been identified. ORNL will continue to work with the Nuclear Physics Program to determine appropriate options for expanding the use of RIBs.

ORNL has also studied other options for an advanced ISOL facility. A cost-effective RIB facility could be constructed by taking advantage of the very high intensity beam of high-energy protons to be produced in the linac of the Spallation Neutron Source. Alternatively, the HRIBF could be upgraded to provide an advanced RIB facility. Both of these options remain open to consideration if funding is not available to construct the RIA facility.

In addition, ORNL is developing, in collaboration with Oak Ridge Associated Universities (ORAU) and several other research partners, a proposal for the design and construction of the Oak Ridge Laboratory for Neutrino Detectors (ORLaND). As discussed in Sect. 4.1.3, ORLaND would be used to study the neutrinos created as a by-product of neutron production in the Spallation Neutron Source (SNS), providing the improved understanding needed to address several outstanding problems in particle physics, nuclear physics, supernova physics, cosmic-ray physics, and solar physics.

5.1.6 • High Energy Physics—KA

ORNL's High Energy Physics Program is focused in three areas: (1) the development of high-power targets for use in projects such as a neutrino factory or a muon collider; (2) the development of particle detectors, including their design and construction; and (3) the development of radiation transport codes and other codes that can be used in the design of particle detectors, shielding, and high-power targets. Current activities include research on the neutrino factory and muon collider with the Fermi National Accelerator Laboratory and Princeton University; work on the BaBar detector with the Stanford Linear Accelerator Center; development of the Oak Ridge Laboratory for Neutrino Detectors (ORLaND), as described in Sect. 4.1.3; target testing at Los Alamos National Laboratory and Brookhaven National Laboratory; and development of the CALOR00 code, a key tool for radiation transport analysis.

5.1.7 • Energy Research Analyses—KD

ORNL assists the Energy Research Analyses program in technical reviews of DOE research programs. This includes technical support for peer review assessments and other studies and workshops as requested.

5.2 • Energy Resources

5.2.1 • Energy Efficiency and Renewable Energy

ORNL's Energy Efficiency and Renewable Energy (EE/RE) Program facilitates R&D on energy efficiency and renewable energy technologies. The major source of program funding is DOE's Office of Energy Efficiency and Renewable Energy (DOE-EE). The program employs an integrated approach to achieve its mission:

- It combines applied research with technology development and deployment activities.
- It draws on the expertise of multidisciplinary teams capable of tackling large and complex problems.
- It involves a wide array of industrial, academic, and public-sector partners in the definition, execution, and assessment of its activities.

This integrated approach is a key element for the Energy and Environmental Systems of the Future Initiative (see Sect. 4.4).

Five energy-related national user facilities are available to researchers: the Automotive Propulsion Technologies Center, the Bioprocessing R&D Center, the Buildings Technology Center (BTC), the High Temperature Materials Laboratory, and the Materials Processing Laboratory User Center.

The EE/RE Program addresses four major R&D areas: buildings, industry, power, and transportation.

ORNL research in **buildings technologies** spans several areas. The BTC is a key resource for these efforts. Heat pump, chiller, and refrigerator technologies are examined to improve energy efficiency and environmental quality. The search for viable ozone-safe alternatives to chlorofluorocarbons (CFCs) has been an important part of both equipment and materials research. Materials research focuses on technologies for high-efficiency, long-lived building systems. ORNL's building envelope research examines how buildings function as an integrated whole—how roofs, windows, walls, and other building elements interact to affect energy efficiency. Researchers also conduct R&D on innovative walls, roofs, and foundations. Retrofits to improve energy efficiency in existing buildings are studied to determine how to obtain the most cost-effective results. A related activity is R&D on improved energy audits and energy use monitoring techniques. Other research areas include manufactured housing, technical assistance with incorporation of innovative materials and technologies in buildings, and hybrid lighting concepts. ORNL also provides technical assistance and evaluation support to DOE's Weatherization Assistance Program.

ORNL provides technical support to the Federal Energy Management Program in the demonstration of new technologies, energy audits in federal buildings, and innovative financing through the Super

Energy Saving Performance Contract to facilitate energy-related improvements in federal buildings in the southeastern United States.

Building Science Research Facility

ORNL has one of the premier buildings research centers in the nation: the Buildings Technology Center (BTC), a designated user facility housed in a cluster of six buildings. The capabilities of the BTC, however, have been stretched to the point that new thrusts can be accommodated only by removing equipment that still has significant technological and economic value.

Expanded laboratory space, controlled field testing, and analytical capabilities are necessary in order for ORNL to continue its successful support of industry and government activities while moving into emerging research areas: the needs linked to strategies for mitigation of global warming; environmentally sustainable buildings; building occupant health; comfort and moisture control; materials and control demands of a digital economy; advanced appliances; building systems integration; and new cooling, heating, and power delivery strategies linked to utility restructuring.

New challenges require new strategies, and new strategies require new capabilities. To maintain its leadership role in buildings technologies, ORNL must have the means to address these emerging challenges.

As part of our Facilities Modernization Initiative (see Sect. 7.3), we are developing a Building Science Research Facility to provide space for expanded and new capabilities that will allow ORNL to keep pace with the drivers propelling the buildings industry into the new century.

This 14,000-m^2 (150,000-ft^2) facility is being planned to provide space for research staff, eight interior laboratories for material and component testing, and outdoor space for model building tests. Conference rooms and a video center will accommodate the growing need for team research, guest workers, and visitor interaction. The facility will be located so as to mimimize security concerns to facilitate its use by industrial partners. It will be proposed as a line-item construction project in the FY 2004–FY 2006 time frame.

With the new capabilities, we will be able to test, analyze, and retest new products and systems; formulate and validate models; and predict the effects of product improvements with a high degree of certainty. The Building Science Research Facility supports the aims of the Energy and Environmental Systems of the Future Initiative described in Sect. 4.4.

The nine most energy-intensive industries—agriculture, aluminum, chemicals, forest products, glass, metalcasting, mining, petroleum refining, and steel—participate in DOE's Industries of the Future initiative, which assists these industries in cutting their nonproductive energy use and environmental costs. In support of DOE's **industrial technologies** efforts, ORNL is working with all of these industries on projects that address science and technology barriers identified by industry in visioning and roadmapping processes. Development of new materials that can better withstand the high temperatures and highly corrosive environments often found in industrial processes is a key area of research. ORNL leads materials R&D for ultrahigh-efficiency, clean, cost-competitive gas turbines. The Laboratory is a partner in three projects, begun in July 2000, to develop advanced materials for industrial gas turbines with the goal of improving the performance of the turbines by increasing their efficiency, durability, and reliability and reducing their emissions, thus making them a good choice for distributed generation. Technology support to the DOE Motor, Steam, and Best Practices Program includes the development of measurement and validation tools and techniques. New equipment and processes are investigated, ranging from improvements in heat transfer equipment to "bioreactors" that convert sugars (instead of today's petroleum feedstocks) to industrial chemicals. Other research is concerned with heat pump and chiller technologies. The integration of ORNL capabilities in separations, bioengineering and biosciences, and chemical processing in the Center for Separations and Chemical Processing, described in Sect. 5.2.2, will support industry needs in energy efficiency and pollution prevention.

During the past several decades, electricity's share of U.S. primary energy use has been steadily increasing; in 1999, energy used to generate electricity accounted for 40% of the nation's total energy consumption. To support DOE's work on **power technologies**, ORNL is helping to find ways of ensuring that electricity is delivered efficiently and safely and that cost-effective renewable resource options are available. Research areas include high-temperature superconductivity; power transmission and distribution; power electronics; development of biopower feedstocks; hydrogen production, use, and storage; geothermal studies; hydropower environmental mitigation studies; electric utility studies; and international energy collaborative programs. ORNL also provides U.S. representation to two projects of the International Energy Agency: the Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), which maintains an international database of successful, demonstrated energy technologies and facilitates information exchange, and the Greenhouse Gas Technology Information Exchange (GREENTIE), which maintains a directory of organizations and technologies that promote the reduction of greenhouse gas emissions.

In 1999, the **transportation** area accounted for about 28% of the nation's energy use and about two-thirds of its oil consumption. Imports of petroleum (almost $67 billion in 1999) and of automotive vehicles, engines, and parts ($180 billion in 1999) account for 24% of U.S. goods imports, while motor vehicle and equipment manufacturing is the largest U.S. manufacturing industry. Transportation is also the source of about one-third of the total U.S. carbon dioxide emissions. Improving the energy efficiency of transportation and lessening the environmental impacts of vehicle manufacturing and operation can play a significant role in reducing pollution and improving the nation's trade balance.

ORNL's broad transportation R&D program, the largest and most diversified in the DOE system. supports not only the needs of DOE, but also those of other federal agencies and industry. The program addresses materials, ignition and combustion, alternative fuels (including biofuels), transportation data and policy analysis, and innovative manufacturing and finishing processes. Most of the DOE-EE transportation R&D is related to the Partnership for a New Generation of Vehicles. Investigations of transportation energy and environmental issues, national transportation planning and policy, military transportation and logistics, and transportation systems engineering, focusing on multimodal national and international transportation systems, are conducted for the U.S. Department of Defense (DOD), the U.S. Department of Transportation (DOT), the U.S. Department of Commerce, the Environmental Protection Agency (EPA), the Bureau of the Census, and other sponsors.

ORNL will continue to extend the application of its capabilities in transportation R&D and technology through activities that capitalize on the synergies of multiple sponsors and industrial partners. The National Transportation Research Center (NTRC), a partnership of DOE, ORNL, and the University of Tennessee (UT), provides a mechanism for promoting and supporting research activities

Figure 5.6
The National Transportation Research Center during construction, August 2000.

focused on major transportation R&D issues related to energy, environment, and security for the nation and the world. The NTRC, which until recently operated as a "virtual" facility, is now located in a new research and user facility in Knox County, between ORNL and UT's Knoxville campus, that has been constructed through a collaborative effort involving DOE, ORNL, UT, and the Development Corporation of Knox County. The NTRC facility comprises several specialized transportation research laboratories and will house approximately 150 research and support personnel. Partnerships within the Oak Ridge Complex (see Sect. 5.6.2.1) and with other public and private agencies and commercial industry will facilitate transportation R&D. A key activity in FY 2001 will be facilitating the development of a technology roadmap for the 21st Century Truck Program, a joint effort that links four agencies (DOE, DOD, DOT, and EPA) with truck manufacturers, power train manufacturers, and academia.

ORNL's extensive resources in hybrid systems, advanced engines, and emissions technologies will support the development of clean and efficient fuels, addressing the goals of the Energy and Environmental Systems of the Future Initiative (see Sect. 4.4). ORNL will seek broader programs in these areas and implement technical advances resulting from past and current programs. A key element of this effort will be the development of expanded resources for carbon composites research.

Carbon Composites Research for Transportation

The use of carbon fiber composites rather than steel for body and chassis components could reduce a vehicle's weight by as much as 60%, significantly increasing its fuel economy and reducing its emissions. Thermally conductive carbon foams are of interest for other automotive applications, such as brakes and radiators.

ORNL has extensive expertise in the development and application of these materials and is DOE's coordinating laboratory for research in carbon fiber–reinforced polymer composites for automotive applications. Currently funded research is addressing low-cost fiber precursor; precursor processing into carbon fiber; polymer composite processing, bonding, finishing, and repair; and durability of polymer composites in automotive environments.

ORNL also has expanding responsibilities in several research areas. New laboratories are needed to support work in fiber preforming and polymer composite molding and expanded R&D on thermally conductive carbon foam.

Partnerships have been established with all of the major players in the carbon composite, carbon fiber, and polymer composite industry. Work is under way to leverage these individual partnerships and create a consortium with a single vision to promote unified growth of the industry.

ORNL has also worked with the automotive industry to prepare plans for the development of carbon fiber–reinforced polymer composites and thermally conductive carbon foams. These plans support the mission needs of DOE and other agencies, particularly the U.S. Department of Defense (DOD), and need to be integrated into DOE and DOD long-range plans.

ORNL is working to develop an expanded program in carbon composites research to support the needs of the automotive industry. The vision for the program is to secure sufficient fiscal resources, staffing, and programmatic leadership to establish ORNL as DOE's national center of excellence in carbon composites for automotive/transportation applications.

Most of ORNL's carbon fiber polymer composites research is now housed in facilities at the Y-12 National Security Complex. ORNL is working to establish a new research facility

Figure 5.7
High-thermal-conductivity graphite foam, which has a thermal conductivity equivalent to that of aluminum at one-fifth of its weight. Developed by ORNL and Poco Graphite, the material received an R&D 100 award in 2000.

focused on all phases of carbon fiber research. This facility would also house new equipment required to support the research needs of the automotive industry. The expectation is that this facility will be constructed with third-party financing. ORNL staff will continue working with DOE program managers to ensure that appropriate budget requests are submitted to provide growth in the research program and procure capital equipment. ORNL will also continue to develop and maintain strategic relationships at all appropriate levels of DOE, other federal agencies, the prime automotive and transportation companies, and their suppliers and collaborators.

The National Energy Technology Scientific Computing Center (NETSC) at ORNL provides computational resources for R&D organizations working with DOE-EE's Office of Transportation Technologies to develop advanced vehicles and alternative fuel technologies. The Center's capabilities in mathematical and numerical modeling provide a wide range of analysis tools to solve real-world problems in materials processing using packaged solutions, intelligent interfaces, databases and libraries, training, computing, and prototyping resources. Access to modeling capabilities is provided through a user center at which industry personnel can use the hardware and software available throughout DOE's Oak Ridge Complex. NETSC is funded by the Office of Transportation Technology as part of the Energy Efficiency and Renewable Energy Network.

ORNL's Bioenergy Feedstock Development Program conducts R&D for both the power sector and the transportation sector. ORNL develops new energy crops with increased yields, pest and disease resistance, and drought tolerance for conversion to fuels and power. The Laboratory also addresses the resource, economic, and environmental issues related to biomass feedstocks. This program serves as the focal point for R&D efforts in the rapidly advancing bioprocessing area, emphasizing (1) bioprocessing systems that will economically produce fuels and chemicals from renewable feedstocks and appropriate waste materials and (2) technologies to deal with environmental concerns resulting from energy-related activities. ORNL addresses technology needs for using biomass in existing power plants to supplement or replace coal and is working with the National Renewable Energy Laboratory to lead the National Bioenergy Center, established in Novemer 2000 to support the development of a viable bioenergy and biologically based products industry.

5.2.2 • Fossil Energy

ORNL is engaged in R&D programs for DOE's Office of Fossil Energy (DOE-FE) that address coal, oil (petroleum), and natural gas. ORNL also provides support for the Innovative Clean Coal Technology Program and for the Strategic Petroleum Reserve.

The ORNL Fossil Energy Program embodies a broad range of research, including advanced structural and functional materials, bioprocessing, combustion, carbon sequestration, gas production and utilization, and oil production and environmental technologies.

The Fossil Energy Advanced Research Materials Program includes (1) development of ceramic composites for high-temperature structural applications; (2) development of high-temperature corrosion-resistant alloys with unique properties; (3) development of functional materials such as hot-gas filters (alloys and ceramic composites), ion transport membranes, and activated carbon materials; and (4) research in corrosion and mechanical properties to understand the behavior of materials in advanced fossil-fueled systems. ORNL has a major technical management role, with the DOE National Energy Technology Laboratory (NETL), in the Advanced Research Materials Program.

ORNL is a major participant in the Advanced Turbine Systems (ATS) Program, which has been jointly planned and executed by DOE-FE and DOE-EE. ORNL has worked with Howmet and PCC Airfoils in the development of processes to fabricate single-crystal turbine blades for large land-based gas turbines. ORNL R&D has focused on materials and fabrication methods for thermal barrier coatings and environmental barrier coatings and on materials evaluation. In an effort involving Solar Turbines Inc. (an ATS Program developer) and ORNL's Advanced Research Materials Program, a major advance was achieved in strengthening the alloy used in a high-temperature recuperator for Solar's Mercury 50 gas turbine and increasing its use temperature. Solar Turbines also leads one of three new projects, begun in July 2000, through which ORNL is working with industry partners to develop advanced material technologies that support the use of gas turbines in distributed generation.

ORNL has provided significant support to the Innovative Clean Coal Technology (CCT) Program. ORNL led the environmental impact analysis activity for the total program, which resulted in publication of the Programmatic Environmental Impact Statement, and conducted environmental impact analyses for several individual CCT projects, notably the Healy, Alaska, project involving a coal-fired power station on the border of the Denali National Park. Materials failure analyses have also been conducted for the CCT Program. Significant and unanticipated materials issues have been addressed and solved.

The ORNL Fossil Energy Program is engaged in three major new initiatives: fuel cells and functional materials; carbon sequestration; and methane hydrates. These areas were identified as offering potentially significant opportunities for new R&D that would take advantage of ORNL talents and competencies. All three support the Energy and Environmental Systems of the Future Initiative described in Sect. 4.4.

The fuel cells and functional materials initiative is focused on materials processing and fabrication of (primarily) solid oxide fuel cell components and ion transport membranes for oxygen and hydrogen generation. ORNL's aim is to become a major participant in the DOE-FE fuel cell program through the Solid State Energy Conversion Alliance (SECA) organized by NETL and the Pacific Northwest National Laboratory. ORNL has been identified as a core team member in SECA and expects to have major roles in materials processing and fabrication and in power electronics, particularly inverter technology.

Carbon sequestration R&D is a rapidly growing component of the DOE-FE R&D program. Appropriations for FY 2000 were almost $10 million, and FY 2001 appropriations are anticipated to be between $18 million and $20 million. Three new projects specifically related to carbon sequestration were funded by DOE-FE in FY 2000. ORNL's Environmental Sciences and Metals and Ceramics divisions are collaborating on a project involving biomineralization for carbon sequestration. ORNL is also a team member of GEO-SEQ, a public-private partnership led by the Lawrence Berkeley and Lawrence Livermore national laboratories. This project is performing R&D to deliver information and technologies for the safe and cost-effective geologic sequestration of CO_2. The third project involves R&D to support optimal selection and delivery strategies to maximize carbon sequestration and reclamation of degraded land using fossil fuel combustion byproducts. This project is a complement to the Center for Research on Carbon Sequestration in Terrestrial Ecosystems (CSiTE) described in Sect. 5.1.2.

DOE-FE's new R&D program in methane hydrates is intended to lead to the safe and environmentally acceptable production of methane from this unconventional source. The program has four topic areas: resource characterization and evaluation; seafloor stability and safety; climate change implications; and production. ORNL organized and is leading a national laboratory council to coordinate research efforts and to promote interlaboratory collaboration on methane hydrates R&D. ORNL is also using Laboratory Directed R&D (LDRD) funds to conduct several projects, including construction of the Seafloor Process Simulator (a 70-L pressure vessel for production and study of methane hydrates), seismic reflection imaging of methane hydrate deposits in the Arctic, molecular dynamic simulations, and computational methods for visualization.

Figure 5.8
The Seafloor Process Simulator in the ORNL Aquatic Ecology Laboratory.

ORNL also proposes to integrate its extensive capabilities in separations, bioengineering and biosciences, and chemical processing to create a comprehensive and accessible international resource for meeting needs in energy efficiency and pollution prevention.

Separations Science and Chemical Processing

Problems in separations and chemical processing challenge industries worldwide. Increasingly stringent requirements for purity are being placed on manufacturers of chemicals, pharmaceuticals, food, and materials. The recovery of chemicals used in industrial processes is both environmentally and economically necessary. Improvements in separations can contribute to better industrial products and efficiency and to maintaining the competitiveness of U.S. industry. Workable designs for new processes depend on accurate design and pilot plant data; the availability of good data also minimizes engineered overcompensation and ensures more efficient use of resources and energy. Many of these problems and challenges for process industries are also concerns across the DOE system.

Oak Ridge expertise in separations and chemical processing was initially developed to meet the challenge of purifying crude uranium and separating isotopes. Work based on separations and chemical processing has continued throughout the Laboratory's history, drawing on expertise in solvent extraction, inorganic membranes, adsorption, ion exchange, field-enhanced separations, and dilute solution chemistry. Chemical processing capabilities include analysis of thermophysical properties, computational chemistry and chemical engineering, 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.

With the most comprehensive separations capabilities in the DOE system, ORNL carries out programs ranging from fundamental research to demonstration projects, supporting programs in DOE's Office of Science (DOE-SC); Office of Nuclear Energy, Science and Technology (DOE-NE); Office of Environmental Management (DOE-EM); Office of Energy Efficiency and Renewable Energy (DOE-EE); and Office of Fossil Energy (DOE-FE). Activities involve 9 of ORNL's 15 research divisions. Industrial, academic, and government interest in ORNL separations capabilities is evidenced by joint research projects and cooperative R&D agreements in areas such as field-enhanced separations, thermophysical measurements, membrane separations of refinery gases, ultrapurification of water, computational chemistry and chemical engineering, bioprocessing, and life-cycle analysis.

A survey of potential industrial users showed 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 many 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 showed that firms are beginning to plan for obtaining needed services.

ORNL is capitalizing on its assets and on the interest exhibited by industry by focusing on separations science and chemical processing as a strategic action. As part of this activity, ORNL has established the Center for Separations and Chemical Processing (CSCP) to coordinate its capabilities, establish collaborations with academia, and extend its capabilities to the industrial sector. The CSCP will provide an integrated program and a user center to support the U.S. chemical industry.

The CSCP draws on the capabilities of a number of ORNL divisions:

- The Chemical Technology Division has wide expertise in separation processes and chemical processing, including bioseparations, field-enhanced separartions, novel separations with unique solvents, and critical separations of a range of nuclear materials, waste and environmental materials, and biological products. This expertise is complemented and enhanced by emerging capabilities in modeling and simulation of separations processes.
- The Chemical and Analytical Sciences Division has strong capabilities in studying the chemistry of separation methods, including the development of separating agents, and in providing important innovative analytical chemistry methods and services.
- The Metals and Ceramics Division has assisted industry in the development and commercialization of hot gas particulate filters made of ceramic composites and novel alloys

for high-temperature gas separations. The division has also developed a novel activated carbon material, the carbon fiber composite molecular sieve, which has outstanding features, including the ability to be regenerated electrically, that suggest a high potential for gas separation and gas storage applications.

- The Instrumentation and Controls Division has extensive capabilities in measurement and control needed for separations R&D and for industrial operations.
- The Computer Science and Mathematics Division and the Computational Physics and Engineering Division have extensive capabilities in modeling and simulation.
- The Environmental Sciences Division is active in soil washing and other environmental separations.
- The Robotics and Process Systems Division has expertise in remotely operated separations processes.
- The Engineering Technology Division has experience in several forms of physical separations.

The CSCP also draws on advanced inorganic membrane technology efforts, now managed by Bechtel Jacobs Company, which are directed toward commercial applications to gas/gas, solid/gas, and liquid/liquid separations.

The CSCP builds on ORNL efforts in separations and will coordinate expansion of these efforts by facilitating participation in new programs proposed by DOE and by industrial firms or consortia. Opportunities include a program for measuring the physical properties of hydrocarbons and other materials important to separations in the petroleum and petrochemical industries, a new effort to solve waste problems for DOE-FE, and other activities such as the DOE-EE Industries of the Future initiative.

The CSCP will include a user center for separations and related topics. As a first step, new capabilities and staff have been added to measure chemical and physical properties. This effort also expands ORNL's involvement in related computational research on chemical and physical properties.

The CSCP will be expanded as resources allow to include facilities for testing separation processes on both laboratory and pilot scales, building on available equipment at ORNL (test loops and test stands) for testing processes, equipment, and instrumentation. These facilities will be available to government, university, and industrial users and will also provide a platform for testing instrumentation and computer analyses of separation systems.

Through these activities, the CSCP provides integration of diverse capabilities, creating a complete and accessible separations competency. The CSCP will maintain a DOE identity, with initial work on a new environmental project for DOE-EM and DOE-FE. Subsequent initiatives will focus first on DOE-EE and then on encouraging industrial participation and support, both through collaborative R&D and through use of ORNL user facilities by individual companies to perform selected separations/processing R&D. The availability of ORNL's facilities, the CSCP focus on industrial interactions, and the closing of many industrial laboratories should combine to foster success in these efforts.

ORNL will take the lead in the CSCP; fruitful cooperation is expected with industries, universities, and other DOE laboratories. Working agreements in separations with leading universities are being developed. A Memorandum of Understanding has been established with the University of Texas, and others are in preparation.

The following actions have been taken:

- A catalog of separations R&D activities, capabilities, equipment, and facilities at ORNL was created (with program development funds).
- The Physical Properties Research Facility, with equipment for measuring thermophysical properties, is operating as a DOE national user facility.
- ORNL has a leadership role in DOE's separations roadmapping activities.
- Funding from DOE-EE, DOE-FE, DOE-SC, and industry for separations-related projects has increased by 20%, to a total of $2 million.

To be complete, the CSCP will require additional equipment and, eventually, a new building. The equipment will be acquired on an incremental basis, but significant capital equipment will be required from time to time. The building will be incorporated in ORNL's plans for future site development (see Sect. 7.3). Projected funding is summarized in Table 5.3. Resources are sought from DOE-FE (Petroleum—AC), DOE-EE

(Industrial Energy Conservation—ED), and DOE-SC (Basic Energy Sciences—KC). Support will also be requested from DOE-NE (Nuclear Energy R&D—AF, Isotope Production and Distribution—ST) and DOE-EM, from other agencies, and from industry sponsors.

Table 5.3
Funding projections for Separations Science and Chemical Processing by fiscal year
(in millions of dollars)

	2000	2001	2002	2003	2004	2005
DOE						
Office of Fossil Energy	1.6	2.0	2.0	2.0	2.0	2.0
Office of Energy Efficiency and Renewable Energy	0.4	0.6	1.0	1.5	1.5	1.5
Office of Science	0.2	0.3	0.3	0.4	0.4	0.4
Industry	0.6	1.0	1.5	2.0	2.0	2.0
Department of Defense	0.4	0.6	0.6	0.6	0.6	0.6
Total	**3.2**	**4.5**	**5.4**	**6.5**	**6.5**	**6.5**

5.2.3 • Nuclear Energy, Science and Technology

ORNL programs for the DOE Office of Nuclear Energy, Science and Technology (DOE-NE) include nuclear energy R&D, space power systems, isotope production and distribution, and uranium management.

ORNL supports DOE's policy and strategy initiatives to define the appropriate role for nuclear energy in the nation's future energy supply. The Laboratory leads DOE-NE's principal R&D activity under the Joint Agreement with Japan's Nuclear Power Engineering Corporation (NUPEC), a cooperative activity that involves the development and demonstration of robotics for surveying and mapping radioactive contamination and decontaminating and dismantling nuclear power plants.

ORNL received FY 2000 funding through DOE's Nuclear Energy Research Initiative (NERI) for a new project on forewarning of failure in critical equipment at next-generation nuclear power plants, which is being carried out in partnership with Duke Engineering and Services. ORNL is participating in another FY 2000 NERI project led by the University of Tennessee. Work continues on projects initiated in FY 1999 (four led by ORNL and one led by the University of Michigan).

ORNL supports the production of parts for radioisotope power systems supplied to the National Aeronautics and Space Administration (NASA), providing the materials processing and precision fabrication required to produce the iridium clad vent sets and the carbon-carbon holders. In support of DOE's evaluation of alternatives for the domestic production of ^{238}Pu for future space missions, ORNL is studying the possibility of meeting long-term needs for an assured supply of ^{238}Pu by irradiation of ^{237}Np targets, both in the Advanced Test Reactor (ATR) at the Idaho National Engineering and Environmental Laboratory and in the High Flux Isotope Reactor (HFIR) at ORNL. Drawing on capabilities and facilities available through its Radiochemical Engineering Development Center, ORNL would fabricate the ^{237}Np targets for both ATR and HFIR irradiations and would provide chemical processing of the targets for material recovery.

ORNL's Isotope Program supplies enriched stable isotopes, selected radioisotopes, and related technical services for research, medical, and industrial applications. The program mission includes the development and evaluation of methods of isotope production and separation. ORNL also provides specialized technical services (e.g., preparation of high-purity isotopes and unique chemical and physical forms).

In September 2000, DOE announced plans to work with the private sector to provide a large-scale source of ^{213}Bi, a short-lived decay product of ^{233}U that has shown promise in the treatment of acute myeloid leukemia and is being evaluated for use in treating other cancers. Small amounts of the ^{213}Bi precursor ^{225}Ac are being supplied by ORNL for clinical trials at Sloan-Kettering Memorial Cancer Center in New York. To meet a near-term DOE commitment to double the supply of ^{213}Bi, ORNL has begun additional extractions of ^{229}Th from the ^{233}U inventories stored in Building 3019 (see Sect. 5.4). Natural decay of the ^{229}Th generates ^{225}Ac, which is shipped to medical research centers for the on-site generation of ^{213}Bi. The separation of ^{229}Th is conducted in the ORNL Radioactive Materials Analytical Laboratory, and the ^{225}Ac is extracted and purified in the Radiochemical Development Laboratory. DOE is expected to issue a request for proposals in early 2001 for commercial processing of ^{233}U to provide the $^{225}Ac/^{213}Bi$ supply for research and cancer therapy.

ORNL supports key objectives in uranium programs through activities such as developing technology and providing systems for the verification of highly enriched uranium blend-down in Russian Federation facilities and serving as lead laboratory for the identification and development of beneficial uses for depleted uranium (DU). Conversion and use or management of the 700,000 metric tons of DU stored at DOE's gaseous diffusion plant sites is a significant challenge. ORNL manages DOE's Depleted Uranium Hexafluoride Program, providing technical support for DU disposition. Activities in FY 2000 include program planning and analysis, R&D roadmapping, and technical support for conversion plant procurement activities. In the longer term, ORNL expects to implement and manage an R&D program to establish the technical basis for use and management of DU. A multidivisional team provides technical support to DOE and assists in the conduct of program activities.

5.3 • Environmental Quality

DOE's general goal for its Environmental Quality business is "to aggressively clean up the environmental legacy of nuclear weapons and civilian reactor R&D programs at the Department's remaining sites, safely manage nuclear materials and spent nuclear fuel, and permanently dispose of the Nation's radioactive waste." DOE's Office of Environmental Management (DOE-EM) provides funding to ORNL for basic and applied research, development, demonstration, and technical support to address environmental management (EM) problems, principally at DOE sites, with increasing emphasis on technology transfer. ORNL supports DOE-EM through the development and implementation of better, safer, and less expensive alternatives to existing technologies, with the aim of providing workable solutions to previously intractable problems.

The mission of ORNL's Office of Environmental Technology Programs is to provide science and technology solutions for DOE environmental cleanup. Work that supports waste management and remedial action projects at DOE's Oak Ridge, Paducah (Kentucky), and Portsmouth (Ohio) sites is coordinated with Bechtel Jacobs Company LLC, which manages DOE's Oak Ridge EM program under a management and integration contract (see Sect. 7.1.5). Much of the R&D, however, serves other specific DOE sites or multiple sites.

The DOE-EM Office of Science and Technology (OST) has identified five major focus areas: subsurface contaminants; transuranic and mixed waste; tanks; nuclear materials, and deactivation and decommissioning. Work is also performed in five cross-cutting areas: characterization, monitoring, and sensor technologies; efficient separations and processing; industry programs; integrated process analysis; and robotics, which is linked to DOE's Robotics and Intelligent Machines (RIM) Initiative. ORNL is the lead laboratory for the Deactivation and Decommissioning Focus Area, supporting planning, execution, and evaluation activities. ORNL also provides field technical coordination for the Efficient Separations and Processing Crosscutting Program.

Recent achievements include robotic technologies for facility decontamination and for retrieving radioactive waste from underground tanks, advances in tank waste mobilization and slurry transport and monitoring, improved separations processes for aqueous waste, new techniques for *in situ* treatment of contaminated soils and groundwater, and faster and more accurate waste characterization. Basic research is improving the understanding of the role of colloids in subsurface transport and retention of contaminants; it has also led to the development of a highly sensitive microsensor for detecting contaminants in various media. Increasing emphasis is being placed on supporting the application of R&D to EM problems through communication and interaction with waste management or remedial action project staff across the DOE complex.

DOE's Environmental Management Science Program, a collaborative initiative of DOE-EM and DOE-SC, sponsors basic research to address long-term technical issues and solve challenging problems presented by DOE's environmental legacy. ORNL is conducting 29 EMSP research projects, 5 of which have been selected for "renewal" for an additional 3 years: (1) development of a compound to selectively extract cesium from waste tanks; (2) collection of fundamental data on the effect of biological material on a variety of soluble subsurface contaminants, with the goal of facilitating contaminant removal; (3) exploration of the use of metal-reducing bacteria for bioremediation of toxic metals and radionuclides; (4) examination of the molecular-level mechanisms of microsensors; and (5) investigation of the relationship between exposure and health. The new Natural and Accelerated Bioremediation Research (NABIR) Field Research Center on the Oak Ridge Reservation (see Sect. 5.1.2) is expected to provide opportunities for joint research programs involving DOE-EM and DOE-SC.

ORNL proposes to increase the scope of Laboratory activities in RIM and broaden their application to long-term needs in manufacturing, hazardous and remote operations, and monitoring and surveillance, with an emphasis on DOE's proposed RIM initiative.

Robotics and Intelligent Machines

The DOE complex of national laboratories and production facilities has been a leader in the fundamental research, development, and application of robotics and remote systems since the mid-1940s. Robotics and intelligent machines (RIM) is a critical technical area for accomplishment of DOE missions, with ongoing activities ranging from basic research through field application of robotic systems for environmental cleanup and defense manufacturing.

RIM is also the focus of a new agency-wide initiative in DOE's FY 2001 budget. This effort draws on *Robotics and Intelligent Machines in the U.S. Department of Energy: A Critical Technology Roadmap* (SAND98-2401, Sandia National Laboratories, October 1998), which defines an R&D path for RIM from the present through FY 2020. The roadmap was prepared by a multidisciplinary team that examined RIM as a critical enabling technology, with the objective of developing a cross-cutting technology strategy for the next 20 years.

Representatives of the nine Program Secretarial Officers with mission needs requiring RIM worked together to define principal needs, providing the application pull for RIM in the DOE programmatic missions. Technology needs were defined by the major DOE laboratories that perform RIM R&D in consultation with the user community across the DOE system.

Initial funding for the RIM initiative is through the Office of Environmental Management (DOE-EM), the Office of Science (DOE-SC), and the Office of the Deputy Administrator for Defense Programs (DOE-DP). For FY 2001, RIM funding is $19.8 million, which will allow the initiation of a program to realize, in the longer term, the full benefits of the visionary RIM roadmap.

The DOE RIM initiative is expected to lead to cost reduction, quality improvement, hazard reduction, and new capabilities for performance of tasks that are impossible for humans. These advantages, in combination with the continuing benefits of "Moore's Law" (which posits that the processing power of computer chips will double

Figure 5.9
Human-strength amplification machine. The machine senses the motion and forces exerted by the operator's hand and duplicates the motion while amplifying the forces.

roughly every 18 months), will drive the rapid deployment of RIM technologies into the world economy over the next decade.

As one of DOE's leading performers of fundamental and applied RIM research, ORNL will support this new program as a major participant in DOE-EM and DOE-SC activities, with a strong supporting role in DOE-DP activities.

Specifically, ORNL will seek new opportunities in (1) fundamental research, primarily for DOE-SC, and (2) applied research to meet the needs of DOE-SC facilities and DOE-EM environmental cleanup programs. Participation in the RIM initiative will contribute to the Laboratory's continuing ability to carry out R&D missions that involve hazardous operations (e.g., accelerators, fusion devices, hot cell operations, environmental remediation).

The Laboratory will play a supporting role, teamed with DOE-DP production and modernization organizations, in performing applied research aimed at enhancing manufacturing activities for DOE-DP. ORNL will also sustain a strong teaming relationship with Sandia National Laboratories and Idaho National Engineering and Environmental Laboratory.

ORNL expects to play a continuing role in R&D, demonstration, and application of remote systems, robotics, teleoperation, and related aspects of RIM through interdisciplinary programs for DOE, DOD, and other sponsors. The Laboratory will also work to expand its DOE-SC funding for fundamental research in RIM and to increase the availability of its RIM-related facilities to support DOE's long-term needs in this critical area. This will include the renovation of the high bay area in Building 7602, which will provide strategic facility capabilities for supporting both fundamental and applied RIM R&D.

ORNL also supports DOE's Nuclear Criticality Safety Program (NCSP), which was developed in response to Defense Nuclear Facility Safety Board Recommendations 93-2 and 97-2. The NCSP is a cross-cutting, multilaboratory program, led by the Office of the Deputy Administrator for Defense Programs with additional funding from other DOE organizations. ORNL efforts are primarily funded by DOE-EM; DOE-SC and the DOE Office of Environment, Safety and Health also contribute to the NCSP budget. ORNL performs the lead role in the Nuclear Data Task of the NCSP by measuring neutron cross sections with the Oak Ridge Electron Linear Accelerator (ORELA), evaluating the measured data with the SAMMY code, and testing the evaluations in conjunction with the Cross Section Evaluation Working Group. ORNL coordinates the work program of the Analytical Methods Task by providing capability maintenance and training and user assistance in the SCALE/KENO code system. ORNL is also performing another NCSP Task, "Guidance for Applicability of Bounding Curves/Data."

5.4 • National Nuclear Security

ORNL's National Security Directorate provides programmatic and organizational focus for Laboratory activities in support of DOE's National Nuclear Security business line. During the planning period, ORNL will focus on growing research programs that support this vital area.

Capabilities developed to support DOE's needs are also applicable to the needs of other federal, regional, and local agencies whose responsibilities include national security, public safety, law enforcement, and other security-related issues. Efforts will be made to capitalize on synergies in these needs to expand the Laboratory's opportunities, as described in Sect. 5.6.2. The Associate Laboratory Director for National Security at ORNL is also the vice president of the Advanced Technologies organization at DOE's Y-12 National Security Complex, with responsibility for several business units that apply the distinctive capabilities of the Oak Ridge Complex to the needs of DOE and other government agencies with roles in national security. This partnership between ORNL and Y-12 will create a number of opportunities for combining the expertise of these two organizations to enhance the nation's safety and security.

5.4.1 • Defense Programs

ORNL's work for the Office of the Deputy Administrator for Defense Programs (DOE-DP) within the National Nuclear Security Administration (NNSA) includes support for nuclear weapons R&D, strategic computing, facility transition, and the Accelerator Production of Tritium (APT) program.

ORNL produces ^{252}Cf in the HFIR through an Industrial Sales/Loan Program co-sponsored by DOE-SC. Transuranium element isotopes are recovered from Mark 42 targets, purified, and used in weapons diagnostics at Los Alamos National Laboratory.

ORNL's Radiochemical Development Facility (Building 3019A) provides shielded, safeguarded storage for the DOE inventory of separated ^{233}U. ORNL is supporting the DOE Integrated Nuclear Materials Program in the decision process for disposition or removal of the ^{233}U inventories from the Laboratory's main campus.

In 1997, the Defense Nuclear Facility Safety Board (DNFSB) issued Recommendation 97-1, "Uranium-233 Storage Safety at Department of Energy Facilities." In 1999, ORNL completed the technical evaluations in response to this recommendation and initiated significant enhancements to the material handling capabilities for ^{233}U in the facility. On June 2, 2000, the DOE approved a management plan submitted by ORNL, *Program Management Plan for the ^{233}U Safe Storage Program at Oak Ridge National Laboratory* (ORNL/TM-2000/105, March 2000). This plan defines a multi-year Inspection and Repackaging Project that would repackage the ^{233}U inventories to meet the DOE standard *Criteria for Packaging and Storing Uranium-233-Bearing Materials* (DOE-STD-3028-2000, July 2000). In August 2000, the facility began supplying ^{233}U to the ORNL Radioactive Materials Analytical Laboratory for extraction of ^{229}Th to supply ^{225}Ac/^{213}Bi for cancer research. In September 2000, DOE announced a new initiative to seek private sector participation in processing the ^{233}U in Building 3019 to expand the supply of ^{213}Bi for medical applications (see Sect. 5.2.3). Program modifications are under way to promote the commercialization initiative.

The goal of the High-Performance Storage System (HPSS) development project is a network-centered system capable of parallel data transfers at rates in the gigabyte-per-second range. The project links ORNL; the Lawrence Berkeley, Lawrence Livermore, Los Alamos, and Sandia national laboratories; and industrial partners. HPSS is an essential component of DOE's Accelerated Strategic Computing Initiative, and ORNL has a central responsibility in the HPSS Storage System Management system.

ORNL supports DOE-DP in the development and use of models to check cost estimates for major weapons complex facilities and assists DOE-DP in independent evaluations of new tritium production alternatives, as well as supporting the APT program.

ORNL also provides environment, safety, and health (ES&H) support related to the cleanup of nuclear weapons manufacturing facilities and provides assistance as needed with emergency preparedness activities. ORNL's Radiation Safety Information Computational Center (RSICC) provides information and technology that contribute to the solution of problems occurring in programs for R&D, military application and stockpile support, and facility transition and technical support. The RSICC also receives funding from DOE-NE, DOE-EM, DOE-SC's Offices of Fusion Energy Sciences and Basic Energy Sciences, the DOE Office of Civilian Radioactive Waste Management, the NNSA Office of the Deputy Administrator for Defense Nuclear Nonproliferation, and the Defense Special Weapons Agency. Its integration of developments in the various programs supports the information and technology needs of all scientists and engineers doing radiation transport calculations.

5.4.2 • Defense Nuclear Nonproliferation

The NNSA Office of the Deputy Administrator for Defense Nuclear Nonproliferation (DOE-NN) supports R&D activities and technical assessments related to national security requirements. Much of this work is performed through partnerships with the Y-12 National Security Complex. Activities 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.

ORNL and Y-12 participate in two efforts sponsored by the DOE-NN Office of Arms Control and Nonproliferation (NN-40): the Initiatives for Proliferation Prevention (IPP) and the Nuclear Cities Initiative (NCI). Through a project established in July 2000 as part of the IPP, ORNL will work with scientists in Kazakhstan, U.S. private industry, and the Agricultural Research Service of the U.S. Department of Agriculture to develop technologies for preventing food contamination.

Under the sponsorship of the DOE-NN Office of Fissile Materials Disposition (NN-60), ORNL is DOE's lead laboratory for nuclear-based technologies for fissioning surplus plutonium in existing power reactors in the United States, Russia, and possibly Canada. ORNL's roles for the disposition of U.S. materials include (1) R&D needed to convert and license U.S. light water reactors (LWRs) for use in turning surplus weapon-grade plutonium into spent fuel and (2) technical support to the DOE procurements of a mixed-oxide (MOX) fuel fabrication facility and irradiation services to burn MOX fuel in commercial LWRs. ORNL was identified in the *Surplus Plutonium Disposition Final Environmental Impact Statement* (DOE/EIS-0283, November 1999) as the preferred site for postirradiation examination of MOX fuels.

Critical research at ORNL includes tests to define compatibility issues associated with interactions between gallium fuel impurities and LWR clad materials. ORNL is also managing a multilaboratory, multinational irradiation test program to demonstrate the feasibility of using CANDU reactors for the fissioning of U.S. and Russian surplus plutonium. ORNL is responsible for managing and cooperating with Russia in developing the technology needed to fission Russian plutonium in Russian and Ukrainian VVER-1000 pressurized water reactors and in performing the design and safety analyses needed to convert the Russian BN-600 liquid metal reactor from a plutonium breeder to a plutonium burner. Finally, ORNL is responsible for the technical effort to assist DOE in collecting and analyzing data for the environmental impact analysis of options for disposition of surplus ^{233}U.

5.5 • Other DOE Programs

ORNL provides support to other DOE offices and installations, including other DOE contractors and operations offices.

ORNL provides support to the DOE Office of Environment, Safety and Health in the categories of oversight, policy and standards, technical assistance, health studies, and information resource management. R&D and technical support activities are coordinated by a program manager and span many ORNL divisions and organizations. Activities include technical standards, criticality safety analysis, performance indicators, occurrence reporting quality, environmental policy and assistance, National Environmental Policy Act (NEPA) compliance, occupational safety and health, facility disposition safety and health support, epidemiology and health surveillance, and business performance systems.

Work for the Office of Policy includes research on transportation, energy efficiency, alternative fuels, fuel economy standards for automobiles and light trucks, and energy options for developing nations. Additional support is provided in regulatory analyses for hydropower development and environmental compliance issues. ORNL also provides support to the Office of International Affairs, which is engaged in building coalitions in support of U.S. foreign energy policy.

ORNL conducts R&D for DOE's Office of Intelligence through Memoranda of Understanding (MOUs) with the National Security Programs Office of the Y-12 National Security Complex.

ORNL supports the Federal Energy Regulatory Commission (FERC) in (1) environmental, economic, and engineering assessments that support licensing of nonfederal hydroelectric projects; (2) studies related to compliance with FERC license conditions or other environmental regulations at existing projects; and (3) technical assistance in other related areas, such as headwater benefits analysis and hydropower benefits in the control of greenhouse gas emissions. 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.

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

5.6 • Work for Other Sponsors

5.6.1 • Overview

The DOE national laboratories can apply their resources and skills to the specific needs of other federal agencies and other customers through DOE's Work for Others (WFO) Program. WFO projects must support the missions of DOE and the individual laboratory and may not compete directly with capabilities available in the U.S. domestic private sector.

ORNL carries out a number of projects for other sponsors, including the Nuclear Regulatory Commission (NRC), the U.S. Department of Defense (DOD), the U.S. Department of Transportation (DOT), the National Aeronautics and Space Administration (NASA), the U.S. Department of Health and Human Services (DHHS), the U.S. Environmental Protection Agency (EPA), the Federal Emergency Management Agency (FEMA), the National Science Foundation (NSF), and the Electric Power Research Institute. Detailed descriptions of current projects are provided in the Supplemental Information appended to this report.

This work serves to broaden ORNL's customer base and provides opportunities for partnerships with universities, industry, other DOE laboratories, other federal agencies, and state and regional organizations. WFO projects often draw on the resources available at other DOE facilities, notably the Advanced Technologies organization of DOE's Y-12 National Security Complex through ORNL's National Security Directorate (see Sect. 5.4). Staff also work closely with the DOE Oak Ridge Operations Office (DOE-ORO) Office of Partnerships and Program Development.

Development of new WFO programs is carried out by individual researchers, by program development staff within ORNL divisions and directorates, and by ORNL senior managers. The Technology Transfer and Economic Development Directorate assists in the development of new programs and provides key services dealing with intellectual property and partnerships.

During the planning period, ORNL will seek to broaden its work for non-DOE sponsors in several key areas. Efforts will focus on maintaining the R&D expertise available to DOE and on identifying and pursuing new opportunities to apply the Laboratory's strengths to mission-related needs, with a focus on emerging areas such as gene function and biotechnology and pressing national concerns such as national safety and security, transportation, and environmental protection. Areas of emphasis are discussed in Sect. 5.6.2.

5.6.2 • Areas of Emphasis

5.6.2.1 • Defense-Related Programs

The structure of the ORNL National Security Directorate combines Laboratory resources with the capabilities of the Advanced Technologies organization at the Y-12 National Security Complex, which comprises several business units that apply the distinctive capabilities of the Oak Ridge Complex to the needs of DOE and other government agencies with roles in national security. Y-12 also has established relationships with many of the Fortune 500 corporations that build systems and components for these agencies.

Among the many unique characteristics of the Oak Ridge Complex is the ability to apply intellectual talent and advanced scientific and manufacturing equipment and material to the basic and applied R&D needed to design, manufacture, and build prototypes. Support for these efforts is provided through the Oak Ridge Centers for Manufacturing Technology and the National Prototype Center, both elements of the Y-12 Advanced Technologies organization. Unique manufacturing facilities can be used by sponsors to prototype or develop new systems and components; modify, miniaturize, or improve current systems and components; or solve problems and challenges that have developed with legacy systems. The

ORNL National Security Directorate is uniquely positioned to integrate technologies and expertise in support of national, regional, and local agencies involved with public safety, law enforcement, and other security-related issues. Partnerships with the National Transportation Research Center (see Sect. 5.2.1) and with other organizations will support activities in these areas.

U.S. Department of Defense

Development of new programs to support the U.S. Department of Defense (DOD) is guided by a strategic plan produced in FY 1998, which outlines a strategy of focusing on selected areas that match customer needs with Laboratory strengths; focusing on larger ($1 million to $5 million), multidisciplinary programs; looking "over the horizon" (at least three years ahead); and targeting key customers within DOD and related defense and national security agencies. Work is under way to expand existing programs and to develop new initiatives.

Ongoing programs include (1) assessment of advanced technology for future military systems; (2) development of advanced materials for improving the structure and survivability of ground vehicles, helicopters, and aircraft; (3) the development of instrumentation and smart sensors for detection of chemical/biological agents, unexploded ordnance (UXO), and terrorist threats and for diagnostics that support weapon system maintenance and life extension; (4) environmental analysis for environmental compliance, cleanup, and management of military sites and for safe dismantling and decommissioning of weapons systems; (5) power systems for future vehicles, facilities, and weapons systems; and (6) modeling and simulation for transportation logistics and operational planning.

Initiatives currently being pursued include

- advanced technology assessment to support the Army's Future Combat Systems and Medium Brigades;
- automotive technology for the 21st Century Truck Partnership, which links DOD, DOE, the U.S. Department of Transportation, and the Environmental Protection Agency with truck manufacturers, power train manufacturers, and academia;
- hybrid electric/diesel and fuel cell technologies for military and commercial vehicles;
- logistics modeling and technology modernization to reduce the logistics demand for military operations; and
- environmentally safe management of military lands and disposal of defense material stockpiles, UXO, and other hazardous materials.

The development of improved technology to defend against the use of chemical and biological weapons will continue to be a major thrust of ORNL's defense-related programs. The need for new means of detecting, preventing, and responding to acts of terrorism using weapons of mass destruction is widely acknowledged. The U.S. Army Soldier and Biological Chemical Command and the U.S. Army Edgewood Research, Development, and Engineering Center will continue to be major supporters of ORNL's work in this area during the planning period. The primary goal of this major Army program activity is to develop an integrated chemical/biological detection instrument that will be fielded by the Army in the next 3 to 5 years. This instrument will also have important potential use in monitoring a wide range of environmental contaminants for the military and civilian sector.

A second major thrust of ORNL's defense programs addresses the military and international concern over land mines and UXO. Detection and disposal of UXO represents a serious and costly challenge for the United States and other nations. A joint DOD-DOE program, aimed at finding new means of detecting, defeating, and removing UXO, draws on resources coordinated by the Interlaboratory UXO Task Force, which was initiated in 1997 by ORNL and Sandia National Laboratories and now involves some 14 DOE facilities and numerous university and industrial partners. ORNL is exploring remote sensing from aerial vehicles and developing computer programs that use remotely collected data to develop images and signatures of concealed ordnance. In work for the Defense Threat Reduction Agency (DTRA), ORNL has also demonstrated that genetically engineered light-emitting bacteria can signal the presence of hidden explosives, offering a potentially cost-effective and safe way of locating antipersonnel mines over a wide area.

The National Security Directorate is responding to the needs of the Joint Logistics Warfighting Initiative sanctioned by the Office of the Secretary of Defense and the Joint Chiefs of Staff. Under this initiative, Oak Ridge will conduct the analytical work required to take advantage of the business process improvements and business rules pioneered by the private sector and apply them to DOD logistics systems. The objective of this effort is to reduce costs and wait times and improve materiel visibility and related status information while providing better decision support tools and a customer-driven logistics system.

Similarly, through the Needs Assessment and Technology Applications Team (NATAT), the National Security Directorate is using its expertise in project management, infrastructure engineering, and systems modeling to support military installation commanders and staffs. By using technology and other techniques from DOE experience, NATAT can provide installations with the tools and capabilities to reduce/avoid costs and have the savings returned to installation managers to improve training facilities and the overall quality of life on military bases.

Defense Advanced Research Projects Agency

The Defense Advanced Research Projects Agency (DARPA) is DOD's central science and technology agency. DARPA supports the development of high-risk, high-payoff technologies and advanced military concepts needed to keep the United States secure. ORNL strengths in materials, biotechnology, microelectromechanical systems, robotics, sensors, and computation are well matched to DARPA's needs. During the planning period, ORNL will continue its efforts to identify new opportunities and improve support to DARPA by providing an increased presence at the agency and expanding the awareness of DARPA needs at the Laboratory.

Cyber Security

Cyber security and information operations are of growing concern to DOE, DOD, and other national security organizations. The systems on which these organizations depend are increasingly threatened by advances in technology and by groups or entities with interests contrary to those of the United States. ORNL will expand its involvement in the development and application of technologies to combat this threat through its National Security Directorate.

National Safety and Security

ORNL has supported the National Institute of Justice, the Federal Bureau of Investigation, and law enforcement agencies with its expertise in chemistry, biology, and computing. Applied R&D for emergency planning capabilities and products is conducted for agencies such as the Federal Emergency Management Agency, the Department of the Army, the U.S. Environmental Protection Agency, and the National Weather Service. Additional opportunities with these and other sponsors will be explored.

The threat of terrorist attacks using chemical or biological agents has heightened attention to emergency management, an area in which ORNL has substantial expertise. ORNL hosted a May 1999 workshop for the Federal Emergency Management Agency, DOE, and DOD and is leading an Oak Ridge Complex effort to integrate and apply capabilities for addressing both natural and man-made disasters.

5.6.2.2 • Aerospace R&D and Technology

ORNL's commitment to securing new roles in aerospace R&D and technology, building on the ongoing programs described in the Supplemental Information appended to this report, is facilitated by Memoranda of Understanding (MOUs) established by DOE-ORO, linking DOE's Oak Ridge facilities to the National Aeronautics and Space Administration (NASA) George C. Marshall Space Flight Center in Huntsville, Alabama, and the U.S. Air Force Arnold Engineering Development Center near Tullahoma, Tennessee. Collaborations will be pursued in such areas as advanced materials and material processes, environmental technology, remote sensing, robotics, space-based global change observation, space launch, and transportation.

A cooperative R&D agreement (CRADA) established in FY 1999 links ORNL and 11 industrial partners in an effort to make improve lightweight carbon fiber–reinforced plastics, which are used in constructing airplanes, spacecraft, automobiles, and other structures because they are stronger but much lighter than steel. This 3-year effort is supported by DOE's Laboratory Technology Research Program, the Air Force Research Laboratory, and NASA's Langley Research Center and by the industrial partners, including aircraft manufacturers, materials suppliers, and materials irradiators.

ORNL is also working with the Human Exploration and Development of Space (HEDS) enterprise (formerly, the Space Exploration Program) at the NASA Johnson Space Center in Houston, Texas. HEDS is engaged in planning to define a technology development program for missions beyond low earth orbit that could be accomplished early in the 21st century. Through a small program development initiative, ORNL is providing support to HEDS in its assessment of technological requirements for a future space exploration program. Work is under way to identify applicable ORNL capabilities that meet NASA's needs (e.g., lightweight, high-strength materials; power management systems; advanced computing; advanced instrumentation; and robotics) and to build relationships between key technical staff members at the Johnson Space Center and ORNL. Over the next two to three years, specific areas of technical support will be identified and a program of support will be initiated.

5.6.2.3 • Health-Related Programs

DOE's mission needs include information about the health effects of legacy environmental wastes, future energy technologies, and chemical and biological weapons. ORNL's programs to address these needs, coupled with its extensive capabilities and expertise in biological and medical science and technology, position the Laboratory to expand its health-related work for other sponsors.

Two emerging efforts, the biomedical engineering program and the Virtual Human project described in Sect. 5.1.2, are expected to support the needs of DOE, other agencies, and the private sector. A number of ongoing programs and collaborations with other national laboratories, academic institutions, medical centers, and industrial partners, including those that support the Complex Biological Systems Initiative described in Sect. 4.2, also offer opportunities for new or expanded efforts to address health-related needs.

5.7 • Laboratory Directed R&D Program

Through its Laboratory Directed R&D (LDRD) Program, ORNL provides 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.

The program operates under the authority of DOE Order 413.2, "Laboratory Directed Research and Development" (March 5, 1997). It is funded by DOE through an overhead charge to all other Laboratory programs. The annual program plan for the LDRD Program, which is prepared and submitted to DOE-SC in accordance with DOE Order 413.2, serves to request LDRD funding for the Laboratory and to provide a general description of and justification for the program. The *ORNL Laboratory Directed Research and Development Program: Annual Report to the Department of Energy Summarizing Fiscal Year 1999* (ORNL/PPA-2000/1, March 2000) provides a program overview, funding summaries, and project summaries for the LDRD Program.

ORNL uses the LDRD Program as a means of funding activities that are expected to enhance the Laboratory's capabilities for carrying out DOE missions. The program has two components: the Seed Money Fund, which supports small projects, and the Director's R&D Fund, which supports larger projects that address specific research areas. In requesting proposals for FY 2001 Director's R&D funds, the UT-Battelle Leadership Team selected research topics associated with the major Laboratory initiatives (see Sect. 4). The selection of these topics reflects ORNL's commitment to managing discretionary resources for strategic change.

Neutron Sciences. The Spallation Neutron Source (SNS) and the upgrades at the High Flux Isotope Reactor (HFIR) that will be completed as part of the major Laboratory initiative in neutron sciences (see Sect. 4.1) offer a unique opportunity for ORNL and the nation to demonstrate world leadership in this area. The success of these projects (and their impact on ORNL) depends critically on the ability to develop the full potential of these new scientific tools and to integrate neutron sciences into research programs across the Laboratory. This target area focuses on five research themes that are essential to leadership in neutron sciences: advanced neutron optics, data visualization and analysis, novel instrumentation concepts, novel applications of neutron scattering, and neutron physics.

Complex Biological Systems. Through its Complex Biological Systems Initiative (see Sect. 4.2), ORNL is developing a significant program that builds on established efforts and expertise in the life and environmental sciences. This initiative involves innovative application of computational, physical, chemical, and engineering sciences to biology and draws on special facilities and resources in analytical technologies, engaging organizations and disciplines across the Laboratory. LDRD projects supporting this initiative address four research areas: genomics-enabled biology, the microbial cell, biological systems analysis, and predictive toxicology.

Terascale Computing and Simulation Science. By enabling the realistic modeling of physical situations, advanced computing and simulation science can provide new insights into a host of scientific problems. ORNL's major initiative in terascale computing and simulation science (see Sect. 4.3) is aimed at expanding the Laboratory's ability to support DOE's missions by accelerating the integration of simulation, modeling, and computation into its R&D programs. This effort includes continuing emphasis on high-end and distributed computing; efforts to increase Laboratory-wide expertise in modeling, simulation, and numerical methods; and enhancements in the accessibility of high-performance computational power. To support this initiative, LDRD projects will address the following research areas: simulation science, high-performance networking, computing system efficiency, and collaboratory software.

Carbon Management. ORNL's Energy and Environmental Systems of the Future Initiative addresses a growing concern that the issue of emissions—particularly, greenhouse gas emissions—may make the continuing use of fossil fuels nonsustainable. Reductions in greenhouse gas emissions will clearly require advances in carbon management; thus, LDRD projects will be undertaken in four key areas: improving the performance of distributed energy resources, reducing CO_2 emissions, removing atmospheric CO_2 through natural and induced sequestration, and developing a comprehensive modeling framework to evaluate carbon management options.

Nanoscale Science, Engineering, and Technology. ORNL's new Advanced Materials Initiative (see Sect. 4.5) is aimed at sustaining the Laboratory's position as a leader in materials science and technology underpinning DOE's energy resources mission. A key aspect of this initiative is the development of a program, supported by an investment of LDRD funds, in nanoscale science, engineering, and technology (NSET).

This is the second consecutive year in which up to $2 million of the Director's R&D Fund has been earmarked for new projects in NSET. This LDRD investment is expected to lead to breakthroughs in many fields central to DOE's missions, including materials science, biotechnology, processing science, energy and the environment, information technology, and national security. Five themes, identified at a January 2000 workshop, provide a strategic focus for the broad range of novel and often multidisciplinary research topics encompassed by NSET. LDRD projects will address these themes: discovery of novel phenomena and processes, materials synthesis and characterization, chemistry and chemical processing, computing and electronics, and nanobiotechnology.

6 • R&D Partnerships and Collaborations

Research and development (R&D) partnerships with other laboratories and with universities, industry, other government agencies, and international research institutions are carried out at the Oak Ridge National Laboratory (ORNL) through traditional collaborative arrangements and increasingly through the development and application of capabilities that facilitate collaboration among geographically separated researchers, or "science at a distance." These partnerships strengthen the nation's science base and are a key element in the UT-Battelle commitment to excellence in community service. Table 6.1 lists a number of major partnerships and collaborations.

Although it is formally a national laboratory, ORNL has a strong role as an *international* laboratory, routinely hosting guest researchers and visitors from other nations. These kinds of partnerships facilitate access to facilities in other nations by U.S. scientists and encourage the globalization of science. In addition, 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 goals in scientific cooperation and technology transfer. In FY 1999, ORNL hosted approximately 3000 scientists and engineers from universities, industries, and other federal institutions. About 25% were industrial guests. Many conducted R&D at one of ORNL's designated user facilities.

UT-Battelle plans to expand the use of partnerships as a means for conducting collaborative R&D, facilitating access to ORNL's distinctive capabilities, improving the utilization of its scientific facilities, transferring technology to industry, and supporting the education of the next generation of scientists and engineers. UT-Battelle, itself a partnership, comprises several key resources for this expansion: the University of Tennessee (UT), a Carnegie Research Level I institution that attracts nearly $80 million annually for sponsored research programs; six "core universities," Duke University, the Georgia Institute of Technology, Florida State University, North Carolina State University, the University of Virginia, and Virginia Polytechnic Institute and State University (Virginia Tech); and Oak Ridge Associated Universities (ORAU), a consortium of 86 colleges and universities that manages the Oak Ridge Institute for Science and Education for the U.S. Department of Energy (DOE) and promotes collaborative partnerships for the benefit of its member institutions.

These resources will be a key to the University Partnerships Initiative that is included in the Laboratory Agenda (see Sect. 3.2). Plans also include the following actions:

- Extend collaborative relationships with other DOE laboratories and facilities, integrating the complementary capabilities distributed across the DOE complex in support of the Department's missions.
- Develop industry partnerships that bring the Laboratory's resources to bear on industrial problems and strengthen the economy by bringing new technologies to the marketplace.
- Build new educational, training, and research partnerships with other federal agencies; with educational consortia and museums, both regionally and nationally; and with private-sector institutions.

6.1 • Laboratory Partnerships

ORNL actively supports the DOE "system of labs" approach and is engaged in numerous collaborative relationships with other national laboratories, as indicated in Table 6.1. Most notable is the Spallation Neutron Source (SNS) collaboration with the Argonne, Brookhaven, Lawrence Berkeley, and Los Alamos national laboratories and the Thomas Jefferson National Accelerator Facility (see Sect. 4.1.1). The SNS project has been cited by DOE as an outstanding example of interlaboratory collaboration.

Table 6.1
Major ORNL partnerships and collaborations

Activity and Partners	Description
Science	
Spallation Neutron Source Argonne, Brookhaven, Lawrence Berkeley, Los Alamos, Thomas Jefferson National Accelerator Facility; the neutron user community (universities and industry)	Design and construction of an accelerator-based facility (total projected cost: $1.4 billion) to provide the world's most intense pulsed neutron beams. Each laboratory is fully responsible for a major component or system and its integration into the facility; this collaborative approach to designing and constructing a major research facility provides a model for future DOE projects.
Center of Excellence for the Synthesis and Processing of Advanced Materials Argonne, Brookhaven, Lawrence Berkeley, Idaho, Los Alamos; Ames	Coordinated, cooperative multilaboratory research partnerships on the synthesis and processing of advanced materials for energy technologies. ORNL is engaged in projects on Mechanically Reliable Surface Oxides for High Temperature Corrosion Resistance, Ultrahigh Temperature Intermetallics, Welding and Joining, Magnet Materials, Metals Forming, Microstructural Engineering with Polymers: In-situ Composites, and Advanced Photovoltaics.
Materials MicroCharacterization Collaboratory Argonne, Lawrence Berkeley; University of Illinois at Urbana-Champaign; National Institute of Standards and Technology; many industrial partners	Interactive virtual laboratory to provide remote access to characterization tools used in materials research and interaction among researchers. Tasks include the definition, development, testing, and procurement of hardware and software for remote collaboration, focusing on microscopy and microanalysis.
Advanced Computational Testing and Simulation (ACTS) research Argonne, Lawrence Berkeley, Lawrence Livermore, Los Alamos, Sandia; University of Southern California	Facilitation of future collaboration across the DOE complex. Participants develop mechanisms, interfaces, and modules that enable flexible interoperability of tool kits, codes, and advanced computing resources for mission-critical DOE problems.
Atmospheric Radiation Measurement (ARM) Program Argonne, Brookhaven, Lawrence Berkeley, Lawrence Livermore, Los Alamos, Pacific Northwest, Sandia; National Renewable Energy Laboratory; other government agencies, industry, universities, and international organizations	Data collection and analysis to enhance the understanding of global and regional climate change. This effort includes the development of methods of data management and information exchange to facilitate future interlaboratory integration.
National Center for Research on Enhancing Carbon Sequestration in Terrestrial Ecosystems (CSiTE) Argonne, Pacific Northwest; universities; other research institutions	Distributed research center for studies of carbon sequestration in vegetation and soils. Researchers study ways to increase carbon storage, extend its duration, and verify and measure the amount of carbon stored.
Joint Genome Institute Lawrence Berkeley, Lawrence Livermore, Los Alamos; Stanford Human Genome Center	DOE-sponsored collaboration in functional genomics and bioinformatics.
Fusion Energy Sciences Argonne, Pacific Northwest, Sandia; Princeton Plasma Physics Laboratory; universities; General Atomics and other industry partners; international partners	Broadly collaborative programs to establish the science base for development of fusion as an energy source. This effort spans collaborations on experiment design and operation (National Spherical Torus Experiment, National Compact Stellarator Experiment, Quasi-Omnigeneous Stellarator), technology development and remote collaborations (Virtual Laboratory for Technology), and high-performance computing.

Table 6.1 (continued)
Major ORNL partnerships and collaborations

Activity and Partners	Description
Science (continued)	
Southern Appalachian Man and the Biosphere Federal agencies; states of Georgia, North Carolina, and Tennessee; Appalachian Regional Commission; Southeast Natural Resource Leaders Group	Public/private partnership promoting environmental health, sustainable economic use, and cultural values across the Southern Appalachians, a component of the Man and the Biosphere (MAB) Program established by UNESCO.
Tennessee Mouse Genome Consortium University of Tennessee, Vanderbilt University, Meharry Medical College, St. Jude Children's Research Hospital	Acceleration of the development and analysis of mouse models for human diseases.
Energy Resources	
Bioenergy Feedstock Development Program National Renewable Energy Laboratory; U.S. Forest Service, U.S. Department of Agriculture, Tennessee Valley Authority; universities; research institutes; industry	Mission-oriented program of research and analysis with a goal of developing and demonstrating environmentally acceptable crops and cropping systems for producing large quantities of low-cost, high-quality biomass feedstocks
Superconductivity Partnership Initiative Argonne; Southwire Co. and other industry partners; electrical utilities	Development, fabrication, and use of high-temperature superconducting (HTSC) electric power systems; a power cable developed through this initiative has been deployed at a Southwire manufacturing facility.
Partnership for a New Generation of Vehicles Other DOE laboratories; other federal agencies, universities; DaimlerChrysler, Ford, General Motors, and other industries	Development of technology that can be used to create environmentally friendly vehicles with up to triple the fuel efficiency of today's vehicles and comparable affordability, performance, and safety.
Industries of the Future Other DOE laboratories and facilities; other federal agencies; universities; industry	Coordination of R&D for energy-intensive materials and process industries; includes development of road maps and creation of broad R&D partnerships.
Applied CarboChemicals CRADA Argonne, Pacific Northwest; National Renewable Energy Laboratory; Applied CarboChemicals	Development of cost-competitive chemical feedstocks from renewable resources.
National Transportation Research Center University of Tennessee; Development Corporation of Knox County	Partnership between the public and private sectors to develop new transportation systems that are affordable and that address the needs of the public in safety, security, and convenience. Specialized transportation research laboratory facilities provide tools for industry and other research partners.
GREENTIE International Energy Agency; member nations	Information network for distributing information on suppliers of technologies that reduce greenhouse gas emissions.
Public Power Institute Tennessee Valley Authority	Mutually beneficial collaborations to develop, demonstrate and deploy technologies for efficient and environmentally beneficial renewable energy production and use.

Table 6.1 (continued)
Major ORNL partnerships and collaborations

Activity and Partners	Description
Environmental Quality	
Consorcio Educativo para la Proteccion Ambientale Argonne, Sandia; two Mexican universities, three Chilean universities, U.S. universities serving Hispanic students; industry	Environmental partnership initiative that provides for joint research, student exchanges, faculty development, curriculum development, creation of bilingual educational materials, and other cooperative activities.
Environmental Management Science Program Other DOE laboratories; universities	Joint DOE-SC/DOE-EM program to reduce the cost and risk of cleanup through targeted basic science research. Projects address a range of environmental problems and draw on expertise from a variety of scientific disciplines.
Strategic Environmental Research and Development Program (SERDP) Pacific Northwest; other DOE laboratories; U.S. Department of Defense, Environmental Protection Agency, other federal agencies	Multiagency program funded through the U.S. Department of Defense to identify, develop, demonstrate, and transition environmental technologies that relate directly to defense mission accomplishment.
National Nuclear Security	
Interlaboratory Task Force for Unexploded Ordnance 14 DOE laboratories and facilities	Support for U.S. Department of Defense and other national and international entities concerned with the detection and disposition of land mines and other forms of unexploded ordnance
Nuclear Criticality Safety Program Argonne, Lawrence Livermore, Los Alamos; Idaho; universities	Development of an improved and integrated DOE capability to predict criticality in nuclear fission systems through new experiments, benchmarking against available U.S. and international data, refinement of Monte Carlo computer models, and processing of nuclear data into standard working forms.
International Nuclear Safety Program DOE laboratories and facilities; Russia and former Soviet Union nations; industry	Identification and development of commercial opportunities for scientists and engineers formerly involved in weapons programs (nuclear, chemical, and biological) of the former Soviet Union. In the Nuclear Cities Initiative, ORNL is paired with Sandia to serve the Russian city of Krasnoyarsk. The Initiatives for Proliferation Prevention program focuses on the Newly Independent States.
U.S./FSU Program of Cooperation on Nuclear Material Protection, Control, and Accounting DOE laboratories and facilities; Russia and former Soviet Union (FSU) nations; universities; industry	Reduction of the risk of nuclear weapons proliferation by strengthening security and developing Material Protection, Control, and Accounting (MPC&A) systems at sites containing weapons-usable nuclear materials.
U.S. Plutonium Disposition Activities DOE laboratories, facilities, and operations offices; industrial nuclear fuel cycle entities; nuclear power plant owner/operators; and nuclear safety regulators	Definition, development, and demonstration of technologies required for the disposition of surplus weapons-grade plutonium.
Joint U.S./Russian Plutonium Disposition Activities DOE laboratories and facilities, Russian research institutes, industrial nuclear fuel cycle entities, nuclear power plant owner/operators, and Russian nuclear safety regulators	Development, demonstration, and licensing of technologies and facilities required to implement plutonium disposition in reactors.

Other notable collaborative efforts include

- the PHENIX detector for the Relativistic Heavy Ion Collider at Brookhaven;
- the Genome Annotation Consortium, through which ORNL is working with Argonne, Lawrence Berkeley, Lawrence Livermore, Los Alamos, several universities, and other research institutions to provide a comprehensive sequence-based view of genomes; and
- the Probe test bed for comparative evaluations of storage-intensive applications, which links computational resources at ORNL and the National Energy Research Supercomputing Center.

6.2 • University Partnerships

Our University Partnerships Initiative is aimed at increasing the value of science and technology at ORNL through active involvement of faculty and students in Laboratory programs. The initiative also supports DOE's commitment to helping to educate the next generation of scientists, engineers, technicians, and educators.

The University Partnerships Initiative builds on ORNL's current involvement in research partnerships with universities, many of which also have a significant education component (see Sect. 8.2). It includes the following elements:

- establishing programs with the six UT-Battelle core universities for joint hiring of scientists and engineers, as a prelude to a program with a wider set of universities;
- working with ORAU to facilitate research partnerships with its member institutions;
- expanding collaborative programs with UT in areas of mutual interest;
- developing new research partnerships with Tennessee colleges and universities, historically black colleges and universities (HBCUs), and prominent universities across the country;
- initiating a summer research program for faculty from HBCUs and other minority educational institutions (MEIs); and
- developing the Oak Ridge Center for Advanced Studies to encourage interactions between ORNL researchers and university faculty and students.

The initiative is expected to support recruitment at the Laboratory, provide additional opportunities for graduate students to conduct research at ORNL, and offer outlets for ORNL staff members for sabbaticals and research appointments.

With roots in the Laboratory's early history, the long-standing partnership between ORNL and UT spans a broad spectrum of R&D and other activities, as indicated in Table 6.2. 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 UT Knoxville and research positions at ORNL. Joint institutes in biological sciences, computational sciences, energy and environment, heavy ion research, and neutron sciences represent additional tools for combining the resources of these institutions for research and education. As described in Sect. 7.3, the state of Tennessee has pledged funding to construct new facilities at ORNL to house three of these institutes. The Joint Institute for Heavy Ion Research is already located in a UT-owned facility at ORNL, and the Joint Institute for Energy and Environment is expected to remain at UT's Knoxville campus.

Figure 6.1
The Joint Institute for Heavy Ion Research, established in 1984 to enhance use of ORNL's Holifield accelerator.

Table 6.2
Interactions between ORNL and UT Knoxville

Joint Institutes:
Joint Institute for Biological Sciences
Joint Institute for Computational Science
Joint Institute for Energy and Environment, with the Tennessee Valley Authority
Joint Institute for Heavy Ion Research, with Vanderbilt University
Joint Institute for Molecular-Based Engineering and Science
Joint Institute for Neutron Sciences
Science Alliance, a Tennessee Accomplished Center of Excellence:
Distinguished Scientist Program
Collaborating Scientist Program
University Graduate Programs that draw on ORNL resources:
Graduate School of Genome Science and Technology (based at ORNL)
Graduate Program in Ecology
Joint Program in Mixed-Signal VLSI and Monolithic Sensors
Academy for Teachers of Science and Mathematics
Advanced Thermal Analysis System Laboratory
Center for Environmental Biotechnology
Composite Materials Science and Processing Laboratory
Measurement and Control Engineering Center
National Transportation Research Center
Netlib, a collection of mathematical software, papers, and databases
Nuclear Structure Theory Program
Project SEE (Satellite Energy Exchange), with NASA Marshall Space Flight Center, the University of Virginia, and the Russian Space Institute
UT-ORNL Select Graduate Fellowship for the Outstanding Applicant in Condensed Matter Physics

Two collaborative activities link ORNL and UT resources with those of other partners to address public and private sector needs in areas of growing importance, both regionally and nationally: transportation and human health.

The National Transportation Research Center (see Sect. 5.2.1) provides resources for the development of new transportation systems, including specialized transportation research laboratory facilities that are available to industry and other research partners. Construction of a building for these resources was undertaken as a partnership with DOE and the Development Corporation of Knox County.

Figure 6.2
Visitors from the UT-Battelle core universities at a May 2000 briefing.

The Tennessee Mouse Genomics Consortium links ORNL, UT, Vanderbilt University Medical Center, St. Jude Children's Research Hospital, and Meharry Medical College (an HBCU) for collaborative research in developing mouse models for human diseases. This arrangement is the result of an initiative undertaken through the Joint Institute for Biological Sciences (see Sect. 4.2.6).

The six UT-Battelle core universities have made major commitments of resources to begin various programs of collaboration with ORNL, including joint faculty, shared research programs, and development of new joint institutes. As part of the

University Partnerships Initiative, UT-Battelle plans to establish additional relationships with major research universities to generate more joint appointments, collaborative research, graduate student opportunities, and regional support for ORNL.

The Laboratory will also continue its interactions with Tennessee's Centers of Excellence program for public higher education, which supports 26 Centers of Excellence and a number of Chairs of Excellence at Tennessee Board of Regents institutions.

ORAU has led the formation of an HBCU/MEI Council to work with the Laboratory on the development of more R&D partnerships between ORNL and HBCUS and other MEIs. An August 2000 awareness meeting on current programs and activities with HBCUs and MEIs engaged the UT-Battelle Leadership Team, division directors, and diversity representatives in a discussion of how ORNL can develop an approach to strengthen future involvement. In addition, ORAU has formed an EPSCoR Council to develop partnerships between the Laboratory and universities from states participating in the Experimental Program to Stimulate Competitive Research (EPSCoR).

ORNL and ORAU also plan to establish the Oak Ridge Center for Advanced Studies to serve as a center of intellectual inquiry and a place of interaction between Laboratory staff and university faculty and students. The state of Tennessee has pledged $4 million for construction of a facility to house this center, which will provide courses to advance the professional competencies of ORNL staff, on-site graduate courses taught by UT and core university faculty, and a "think tank" where ORNL and outside experts can carry out intensive studies of special topics in science and technology.

ORNL is working to expand its partnerships with other colleges and universities in the region. In April 2000, library agreements with Pellissippi State Technical Community College and Roane State Community College were signed, giving the faculty and selected students of the colleges access to ORNL's Central Research Library and use of the collections of ORNL libraries. Likewise, ORNL staff have access and borrowing privileges at the two community colleges' libraries.

Academic outreach is also reflected in subcontracted R&D with university partners, which was estimated at $28 million in FY 2000. This included about 10 subcontracts with HBCUs and MEIs, representing funding of about $600,000.

6.3 • Industry Partnerships

ORNL supports DOE's efforts to advance the nation's economic security by leveraging industrial and government resources to address industrial problems and by encouraging more effective use of the DOE facilities by external groups.

ORNL is an active partner in several industry consortia, including the Partnership for a New Generation of Vehicles (PNGV), which supports cooperative projects involving programs in DOE's Office of Science, Office of Energy Efficiency and Renewable Energy (DOE-EE), and Office of the Deputy Administrator for Defense Programs. ORNL is also pursuing the implementation of partnerships with companies and consortia representing the industries participating in the DOE-EE Industries of the Future initiative. A cooperative R&D agreement (CRADA) established in FY 1999 links ORNL and 11 industrial partners in an effort to improve lightweight carbon fiber–reinforced plastics and reduce the cost of these materials. In April 2000, ORNL signed a memorandum of understanding with Secat, Inc., of Lexington, Kentucky. Secat is a University of Kentucky–affiliated, for-profit company that serves as a technical forum for the aluminum industry. The agreement also includes Argonne National Laboratory and DOE's Albany Research Center.

Partnerships to transfer ORNL's knowledge and technology to the private sector support the creation of new businesses and strengthen the economy. The Laboratory's activities in technology transfer are described in Sect. 8.1.

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7 • Operations and Infrastructure

Since April 1, 2000, the Oak Ridge National Laboratory (ORNL) has been managed for the U.S. Department of Energy (DOE) by UT-Battelle, a partnership between the University of Tennessee (UT) and Battelle. The UT-Battelle Leadership Team comprises the Laboratory Director; the Deputy for Science and Technology and the Deputy for Operations; four Associate Laboratory Directors (ALDs) with line responsibility for ORNL's research and development (R&D) missions; and seven support directors, who are responsible for establishing the policy and tools and maintaining the subject matter expertise that enable the ALDs to execute their operational responsibilities in delivering on the Laboratory's mission assignments.

UT-Battelle is committed to simultaneous excellence in science and technology; laboratory operations and environment, safety, and health (ES&H); and community service. This commitment guides our approach to continuing the safe, secure, and cost-efficient operation of ORNL. The Laboratory Agenda (see Sect. 3.2) outlines how we will sustain and improve the Laboratory's ability to serve the needs of DOE and the nation through responsible stewardship of the resources entrusted to our care. Specific plans for delivering improvements in Laboratory operations and ES&H are discussed in this section.

7.1 • Environment, Safety, and Health

UT-Battelle is committed to protecting ORNL's workers, the public, and the environment. To this end, our philosophy is to embed ES&H practices in the work process, so that outstanding ES&H performance is achieved as an integral element of doing the work of the Laboratory. This will be accomplished by clearly assigning line accountability for ES&H; enabling line management and workers with effective, efficient processes and tools; and providing field-deployed ES&H subject matter experts to support the work. This approach incorporates our commitment to the core functions and guiding principles of integrated safety management (ISM), which we have extended to other areas (e.g., safeguards and security).

7.1.1 • Goals and Objectives

Our primary goal is to establish efficient work processes and instill cultural behavior that produce outstanding ES&H performance as a natural part of doing work. We will achieve this goal by building on the successes of the past. Through our Enhanced Operational Discipline Initiative, we will enhance ORNL's overall operational performance by improving the discipline and integration of our operations. Key objectives are

- building on the Laboratory's ISM program to extend implementation to the benchtop, incorporating comprehensive work planning with tailored hazard controls;
- establishing aggressive self-assessment, on-line lessons learned, and robust management of corrective actions to drive continuous improvement at the work activity level; and
- emphasizing environmental protection in ISM to reduce environmental vulnerabilities, enhance waste minimization, and empower waste generators to assume responsibility for the materials that they use and the waste that they produce.

7.1.2 • Current Conditions

Federal and state regulations, permits, applicable DOE requirements, and a Federal Facility Agreement (FFA) among DOE, the state of Tennessee, and the Environmental Protection Agency provide a framework for actions to protect human health and the environment, achieve compliance with environmental regulations, and meet public expectations.

Established in 1943, 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. Contamination of surface water, groundwater, and biota has also been detected and reported. Remediation and waste management activities relating to these issues have been under way for several years. In 1998, responsibility for these activities was transferred to Bechtel Jacobs Company LLC as part of the management and integration (M&I) contract for DOE's environmental management (EM) programs in Oak Ridge.

ORNL is engaged in basic and applied R&D in all of DOE's major businesses. The Laboratory 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 and maintained for accelerators, X-ray units, sealed radiation sources, and radioisotope production, handling, and use. Nonradiological hazards include electrical systems, hoisting and rigging operations, chemicals, biohazards, moving machinery, moving vehicles, construction activities, and natural phenomena such as severe weather.

ORNL also operates one reactor, the High Flux Isotope Reactor. Several other reactors have been permanently shut down and are awaiting deactivation and decommissioning. Several isotope production facilities have also been shut down because of changing missions, 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. More than 35 facilities at ORNL are used by Bechtel Jacobs 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 is implementing an ISM system (ISMS). Each line organization has at least one ISMS plan to customize the ISMS principles and core functions to its operations. Organizations with complex or special-hazard situations have additional ISMS plans tailored to specific programs or facilities. An ORNL self-assessment to confirm readiness of the Laboratory's ISM program was submitted to DOE in February 2000. Phase I verification has been successfully completed. Phase II verification was conducted in March 2000; the results indicated the need for additional work in several focus areas. A Phase II follow-up review in September 2000 verified implementation of the Laboratory's ISMS.

7.1.3 • Plans

Through our Enhanced Operational Discipline Initiative (see Sect. 7.2.1), we are working to develop an integrated set of "systems-based" management systems covering all aspects of Laboratory business. As part of this effort, we will develop systems and tools that support the embedding of environment, safety, health, and quality (ESH&Q) practices and principles into the benchtop work planning and execution process, so that ESH&Q becomes a natural element of doing work. Field-deployed subject matter experts will provide support to customers through a "purchased service" model. The expectation is that this system will reduce costs, improve customer service, and enhance the Laboratory's ES&H performance.

Annual ES&H, quality, and infrastructure (ESHQ&I) budget formulation plans and submissions provide detailed documentation of plans for ensuring ES&H compliance.

Revitalization of the Laboratory's facilities to reduce the safety and health risks created by outdated infrastructure will be carried out through the Facilities Modernization Initiative described in Sect. 7.3.

7.1.4 • Environmental Management Activities

EM activities at ORNL are managed by Bechtel Jacobs. A Record of Decision (ROD) for cleanup of the Melton Valley Watershed was signed in September 2000. The ROD on future remedial actions in the Bethel Valley Watershed is now being finalized. ORNL has participated as a stakeholder in these decision processes. The Laboratory's ESH&Q Directorate will continue to work with Bechtel Jacobs and DOE's Oak Ridge Operations Office (DOE-ORO) to ensure effective remediation of legacy contamination. Environmental restoration activities in the Bethel Valley Watershed, which includes the ORNL "main campus," could have a significant impact on Laboratory operations.

The decommissioning of expensive and aging infrastructure is critical to our Facilities Modernization Initiative. It is essential to ORNL's future that the EM mission at ORNL continue to receive priority support and attention.

7.1.5 • Waste Management Activities

Waste management activities at ORNL are managed by Bechtel Jacobs. The Environmental Protection and Waste Services Division in the Laboratory's ESH&Q Directorate provides the interface between ORNL waste generators and the Bechtel Jacobs waste disposition contractors.

The Bechtel Jacobs approach to M&I implementation focuses on low-cost, fixed-price contracting of EM work scope to qualified vendors. This approach brings with it a number of. issues that could have significant effects on ORNL, such as vendors' ability to operate the complex ORNL waste management infrastructure in a safe and compliant manner, respond to our waste generators, and be flexible enough to accommodate the changing waste needs of a multiprogram laboratory.

Responsibility for management of newly generated waste may be transferred from DOE's Office of Environmental Management to the Office of Science (DOE-SC) in the FY 2001–FY 2002 time frame. ORNL is planning for execution of the responsibilities associated with this transfer.

7.2 • Management Practices

7.2.1 • Performance-Based Management

The management and operation (M&O) contract between DOE and UT-Battelle provides for the use of performance measurement to promote continuous improvement and provides a basis for evaluating contractor performance. ORNL and DOE-ORO have worked together to develop the FY 2001 Performance Evaluation Plan, which links the strategic objectives of the Laboratory Agenda with DOE's performance expectations in the areas of science and technology, leadership, business operations, ES&H, infrastructure, and stakeholder relations through a set of performance goals, measures, and indicators. The Performance Evaluation Plan is incorporated into the M&O contract.

ORNL is committed to self-assessment of all business activities as a mechanism for evaluating the overall effectiveness of ORNL organizations and promoting continuous improvement. In addition, DOE-ORO views the Laboratory's self-assessment program as a primary tool for performance measurement. The Performance Evaluation Plan calls for the delivery of a Laboratory-level self-assessment plan to DOE's ORNL Site Office and DOE-SC during the first quarter of FY 2001, followed by regular updates on performance, a formal status briefing at midyear, and a formal self-evaluation report to the ORNL Site Office at year's end. Self-assessment plans are also being developed and maintained at the division and directorate level, and year-end self-evaluation reports from divisions and directorates will be used in compiling the Laboratory-level report, as will the results of external assessments, internal audit reports, independent oversight, and customer survey data.

ORNL is implementing a Performance-Based Management System (PBMS) to expand the existing self-assessment program beyond ESH&Q compliance to an integrated system that provides for the assessment of all aspects of ORNL business. The PBMS will provide a means to

- interface with customers and stakeholders to determine the direction of the Laboratory through the development of performance objectives and indicators,
- develop methods to monitor performance against those objectives and indicators through creation of assessment plans,

- compare performance with expectations using tools defined in the various elements of the PBMS, and
- implement improvements identified through the performance assessment process.

The PBMS is one element of an integrated set of "systems-based" management systems to be developed and deployed as part of our Enhanced Operational Discipline Initiative. The end result will be an integrated system for monitoring, assessment, and improvement of the Laboratory's performance.

7.2.2 • Human Resources

ORNL's Human Resources and Diversity Programs Directorate provides consultation, advice, and support to line organizations in several areas of human resources, including recruitment and staffing, compensation and performance management, personnel and labor relations, benefit management, employee and organizational development, human resource information systems, workforce diversity, and ad hoc consulting services. The Directorate is committed to delivering value-added, customer-focused, cost-effective services to all Laboratory organizations. Its goal is to develop and maintain systems, programs, and policies that best enable ORNL to achieve its vision of simultaneous excellence in science and technology; laboratory operations and ES&H; and community service.

The Directorate continually reviews and evaluates its programs and approaches to ensure that efforts are appropriately aligned with and achieving results consistent with current initiatives, near-term critical outcomes, and longer range strategic objectives. A number of activities have been or are being undertaken to establish ORNL as an employer of choice in the research community and the region, supporting the Maximizing Research Effectiveness Initiative on the Laboratory Agenda. Special emphasis is placed on enhancing our ability to attract and retain employees with critical skills, increasing the diversity of the work force, and identifying and implementing progressive work-life programs. These activities are summarized in Sects. 7.2.2.1–7.2.2.5.

7.2.2.1 • Human Resources Information System

A human resources information system (HRIS) developed as part of the SAP R/3 project (see Sect. 7.2.5) was implemented in October 1999. This system will be the primary mechanism for processing employee transactions. More importantly, HRIS will be a management information platform to give line organizations ready access to employee demographic and labor cost information, supporting management decisions. Near-term efforts will focus on maximizing the potential of SAP and implementing system improvements.

7.2.2.2 • Staffing Management and Workforce Diversity

In April 2000, staffing functions were merged with the Office of Workforce Diversity to form the Staffing Management and Diversity Programs Division. This restructuring will enhance staffing coordination and support efforts to provide the Laboratory with a diverse pool of candidates for employment, thus supporting ORNL in meeting two notable challenges for the planning period: "recapitalizing" the Laboratory's human resources pool and increasing the presence of minorities and women in senior management and senior individual contributor and researcher roles, a key UT-Battelle commitment.

The average age of Laboratory staff members is approaching 50, and significant numbers of employees can be expected to retire in the next several years, taking with them vast amounts of technical knowledge and corporate memory. This challenge will be met through a comprehensive staffing management approach that includes

- identifying critical skill and knowledge requirements;
- evaluating turnover patterns to identify vulnerabilities;
- providing an effective performance management component;
- ensuring the implementation of competitive strategies to retain, attract, and reward those with critical skills;

- addressing employee "quality of work life" issues; and
- providing approaches to ensure a transfer of knowledge from our experienced contributors to those who will take on the challenges of the future.

The Staffing Management and Diversity Programs Division is working with line management to develop a multifaceted approach to increasing the diversity of the senior management and senior research staff. Efforts include capitalizing on succession planning and employee development and leadership programs to better support the identification of current and future critical skills and the communication of staffing needs. The directorate's Employee and Organizational Development Group serves as the process lead, but this will be a collaborative effort involving other groups within the directorate and line management. The directorate will also be working closely with line management to strengthen and build on relationships with Historically Black Colleges and Universities (HBCUs) and other potential recruitment sources to direct current and future candidates to ORNL.

ORNL has been recognized by DOE and the Office of Federal Contract Compliance Programs for significant progress in addressing Equal Employment Opportunity/Affirmative Action (EEO/AA) and promoting a harassment-free workplace. The Laboratory is committed to achieving its strategic business objectives by capitalizing on the diversity of its workforce. In addition to its annual Affirmative Action Plan, which assesses progress toward meeting annual objectives, ORNL has established a Diversity Plan that outlines a means for promoting a high-performance, diverse, and inclusive organization. This approach ensures development of clear objectives, establishes roles and accountability, and provides for a critical assessment of results.

ORNL will continue working to recruit, retain, and develop a diverse workforce; to promote understanding and valuing of differences; to create an environment that accommodates the future workforce; and to ensure that the required skill sets and employee resources are available to support the Laboratory's business and research objectives. Strategies under consideration include the development of more flexible work schedules, an on-site child care facility, and other "quality of work life" issues.

The Staffing Management and Diversity Programs Division also manages ORNL's Employee Concerns/Response Program, which provides a means for management to learn about and understand employee concerns. The program also serves to ensure that all employees know that their concerns and suggestions will be taken seriously and feel free to voice them. Key aspects of the program include an easy process for submitting suggestions and concerns, a specified time frame in which the employee's concern should be addressed, a two-step appeal process, and an alternative dispute resolution process.

7.2.2.3 • Performance Management and Compensation

The first phase of a new performance management and compensation system has been implemented with the introduction of the Performance and Development System (PADS). This Web-based system will serve as the foundation for a new competency-based performance management system that aligns ORNL strategies with underlying job competencies that have been identified, defined, and communicated to all employees. A new and simplified job worth and pay system is under development. The objective is to place the responsibility and accountability for most employee performance and salary decisions with line management. Information, tools, and guidelines to support line managers in this area have been introduced, as well as analyses, summary overviews, and reporting of results for Leadership Team review.

Increasing the competitiveness of ORNL's R&D salaries has been identified as a key strategy for the Laboratory. A plan is now in place to strengthen the R&D salary program in target areas where the Laboratory is not competitive. We plan to continue and extend this effort to address the lack of competitiveness for non-R&D salaries. Specific steps to be taken include (1) aggressively continuing the R&D market adjustment program, (2) completing the implementation of the new job worth and pay system, (3) addressing the noncompetitiveness of salaries in the non-R&D areas, and (4) evaluating the market competitiveness and flexibility of our benefit plans. This will be a significant challenge, given our commitment to driving down cost (see Sect. 7.2.5), but we believe this to be a critical area for ORNL.

7.2.2.4 • Employee and Organizational Development

ORNL continues to strive for best-in-class leadership development performance. The Laboratory's core program for middle managers is the Leadership ORNL Program; 233 participants have completed this program since its inception in November 1997. The Oak Ridge Leadership Action Consortium (ORLAC) is a forum where Leadership ORNL participants and others can network and support positive changes through team projects.

Two recent additions to the ORNL Leadership Alive curriculum are the Project Management Survival Skills workshop and the Leadership, Enhancement and Development (LEaD) Program for front-line supervisors, group leaders, and prospective leaders.

An area for future emphasis is an enhanced career development program designed to support employees with their future interests and align their interests with ORNL's mission and vision, as appropriate. Improvements to the succession planning process will include systems, processes, training ideas, and other support actions for enhanced career development for successor candidates and other high-potential employees.

7.2.2.5 • Employee Benefit Programs

In April 2000, ORNL entered into a formal agreement under which Lockheed Martin Energy Systems, Inc., then the M&O contractor for the Oak Ridge Y-12 Plant, essentially served as a third-party administrator for ORNL health benefits and welfare and retirement savings plans. This approach best ensured a smooth and uninterrupted transition of benefits under UT-Battelle and will continue with BWXT Y-12, which became the M&O contractor for Y-12 in November 2000. The 3-year agreement will provide the Leadership Team with the opportunity to review the benefit plan requirements of the Laboratory and develop benefit plans that provide the most efficient and cost-effective delivery of benefits to Laboratory employees (see Sect. 7.2.2.3). During this period, the Laboratory will be fully and equally represented on the benefit administration and investment committees to ensure that ORNL's interests and assets are given appropriate consideration.

7.2.3 • Security, Intelligence, and Nonproliferation

ORNL is committed to protecting cutting-edge research, national security interests, proprietary information, personnel, property, and the general public. The Laboratory fully supports DOE's efforts to strengthen counterintelligence and security at its facilities. Safeguards and security measures are focused on producing an overall security posture that is appropriate to ORNL's research missions and activities.

A graded approach that incorporates threat analyses, risk assessments, and cost/benefit analyses is applied to ensure appropriate protection of all security and safeguards interests, including classified and sensitive unclassified material and information, special nuclear material (SNM), and other U.S. government property. Threats to these assets and interests include compromise, loss, theft, diversion, espionage, sabotage, subversion, and other malevolent or inadvertent acts that may cause unacceptable risks to national security, economic advantage, worker or public health and safety, or the environment.

ORNL has a Site Safeguards and Security Plan (SSSP) and specialized security plans to address both routine operations and contingencies. Programs are in place to ensure physical security, property protection, nuclear material control and accountability, personnel security, information security, and computer and network security. Strategies developed and implemented to ensure the protection of site security interests are designed to assure the required levels of protection, while accommodating the multipurpose R&D missions of the Laboratory. Programs are also developed as needed to assess the potential for radiological or toxicological sabotage and mitigate the potential consequences of such events.

Under a prime contract with DOE-ORO, Wackenhut Services, Inc.–Oak Ridge (WSI-OR) provides selected protective security services for the Laboratory. Overall programmatic responsibility for management of most major security programs remains with ORNL, with the notable exception of the protective force situated at the Laboratory. The purpose of the WSI-OR prime contract with DOE-

ORO, which was established in January 2000, is to provide the appropriate numbers of qualified personnel to support selected protective services activities at ORNL.

ORNL works in concert with WSI-OR to ensure proper protection of DOE interests at the Laboratory. The ORNL Security organization also partners with ORNL line organizations, customers, and DOE to develop and maintain appropriate, cost-effective security systems and procedures for addressing protection issues.

Relatively little work that must be shielded or protected for reasons of national security is conducted at ORNL. During the planning period, the Laboratory will continue working to ensure that safeguards and security measures are focused where appropriate and to configure the security perimeter of the site so that required levels of protection are provided to security interests with the minimum hindrance to the flow of people, equipment, and material throughout the site. Moving to a building-based security perimeter, using technology (e.g., electronic card readers) to control access as appropriate, is being explored.

ORNL costs associated with safeguards and security have risen as a result of the prime contract with WSI-OR, primarily because of the need for WSI-OR to establish a management infrastructure (previously provided by the M&O contractors) in Oak Ridge. This represents an additional challenge to our efforts to drive down the cost of doing business (see Sect. 7.2.5). The move to a building-based security perimeter would reduce protective requirements and should decrease costs once the needed technology (to be funded through reductions in protective requirements) is in place.

A full-scope safeguards and security inspection of ORNL was conducted by DOE's Office of Independent Oversight and Performance Assurance in June 2000. The overall rating for the Laboratory was "Satisfactory"; corrective action plans are in place to address several findings documented in the inspection report. Most of these concerned the protection of unclassified sensitive information at ORNL, an R&D facility with numerous user facilities that also hosts a rather large number of foreign national visitors and guest assignees. Additional measures are being implemented to ensure that protective measures for unclassified sensitive information are consistent with DOE standards and that the accessibility of such information to ORNL's foreign national visitors and assignees is properly controlled.

7.2.3.1 • Intelligence and Counterintelligence

Measures are in place to deter and neutralize foreign or industrial intelligence activities directed at or involving DOE programs, facilities, technology, personnel, unclassified sensitive information; and classified matter at ORNL. The ORNL-based Office of Counterintelligence provides support to the DOE Oak Ridge complex. The office tracks probes for classified, sensitive, or proprietary information by unauthorized personnel; personnel seeking unauthorized access; and compromising behavior on the part of site personnel. This office also handles briefing and debriefing of ORNL staff who are traveling to other nations, with an emphasis on travel to sensitive countries, and provides training to ORNL hosts for foreign national visits and guest assignments to the site to ensure that hosts are fully cognizant of their responsibilities with respect to these visitors and temporary assignees to the Laboratory.

7.2.3.2 • Physical Security

Protective force operations at ORNL are provided by WSI-OR under a prime contract with DOE-ORO. Operations for ORNL are designed to keep the facility, its employees and visitors, and all government property safe and secure while maintaining a "user-friendly" atmosphere with minimal impact to operations. The physical security team in the ORNL Security Department provides an integrated, site-specific safeguards and security program that includes programs for protecting critical infrastructure, SNM, and other government assets, including classified matter, controlled substances, precious metals, and other sensitive items.

Protection of DOE property and unclassified facilities is provided by policies, strategies, and physical protection measures detailed in the *Property Protection Policy Guide for the Oak Ridge National Laboratory* (ORNL-LS-G3, December 1998). The protection of SNM and classified matter security interests is addressed in both the Site Safeguards and Security Plan and a Site Security Plan. Elements such as access controls, protective forces, barriers, and the Property Management System are integrated in a graded program that provides appropriate levels of protection for facilities and property. The Laboratory Protection Division assists organizations in developing protection elements tailored to fit the needs of their operations while providing protection in accordance with DOE and ORNL requirements and guidance.

As described in Sect. 5.4.1, Building 3019 at ORNL provides shielded, safeguarded storage of ^{233}U. Defense Nuclear Facility Safety Board Recommendation 97-1, "Uranium-233 Storage Safety at Department of Energy Facilities," is being implemented through the ^{233}U Inspection and Repackaging Project, which provides for the inventory, inspection, and repackaging (as needed) of materials stored in Building 3019. Additional protective force staffing will be required during the project to ensure that security requirements are met.

The ORNL Security Department, WSI-OR representatives, and the ORNL Chemical Technology Division have developed contingency security planning for the phased implementation of this project. During an early stage (expected to begin around August 2000), Category III quantities of SNM stored in Building 3019 will be accessed, and some additional security measures will be applied with available resources. Later, Category I quantities of SNM will be accessed, and additional protective force staffing will be required. DOE's Office of the Deputy Administrator for Defense Programs will fund the costs associated with both additive security requirements and operational issues involving the ^{233}U Inspection and Repackaging Project.

Moving to a building-based security perimeter, using technology (e.g., electronic card readers) to control access as appropriate, is being explored. This action should reduce the cost of physical security, improve access for guests and visitors, enhance the protection of unclassified sensitive information, and simplify and strengthen processes supporting foreign national visits and assignments.

7.2.3.3 • Information Security

Protection and control of classified and sensitive information includes the following elements:

- Operations security (OPSEC)
- Classified matter protection and control (CMPC)
- Technical surveillance countermeasures (TSCM)
- Classification and information control

All of these elements are addressed in Laboratory directives.

The Security Department manages the information security function to ensure appropriate levels of protection against unauthorized access, loss, or compromise of classified matter under the purview of the Laboratory. The ORNL Internal Security Team Leader assures the viability of an integrated system of information security activities, programs, systems, and policies to assure the protection of sensitive technological and proprietary data as well as classified information. This system includes the ORNL OPSEC program.

Classification of information is overseen by the ORNL Office of Technical Information and Classification, which also supports the protection of export control information and, in reviewing information, maintains an awareness of intellectual property issues. The ORNL Technology Transfer and Economic Development Directorate and the General Patent Counsel within the ORNL Legal Directorate also contribute to ensuring the protection and effective management of the Laboratory's intellectual property.

7.2.3.4 • Cyber Security

The Computer and Network Security (CNS) group in ORNL's Computing, Information, and Networking Division is responsible for both unclassified and classified cyber security programs at ORNL. This group was established in 1997 to provide a dedicated ORNL resource for responding to the emerging challenges of cyber security. It draws on a long history of effective and aggressive cyber security at ORNL. The Laboratory's technical expertise is a key resource in staying ahead of the technical challenges in this area.

The CNS mission is to protect information on ORNL automated information systems (AIS), commensurate with the risk of loss and harm, and to protect access to and from AIS on the Oak Ridge Network. CNS staff work with personnel in the Computing, Information, and Networking Division; the Instrumentation and Controls Division; and the designated division computer security officers (DCSOs) within each ORNL division to ensure computer security, including reviews of division computer equipment and systems.

To optimize its cyber security program, ORNL must balance three obligations:

- protection of resources and information from unintended use or modification;
- openness of resources and information for authorized public and collaborator access; and
- effective use of funding.

An integrated security feature on ORNL's internal web server, "Doorkeeper," reduces the risk of unauthorized access to access-controlled pages. Intrusion attempts are reported to DOE's Computer Incident Advisory Capability (CIAC), with "cease and desist" messages sent to offenders. Users of the central electronic mail system are aggressively protected from viruses at the server level. This saves computer users a great deal of effort compared to the experience at other institutions.

Robust and ubiquitous remote access to the Laboratory's user facilities is an essential element in the "virtual laboratory" concept. This access is necessary to support ORNL's science mission and is essential to working with subcontractors and other partners over the Internet. To support this requirement, ORNL has implemented an enterprise-scale Virtual Private Network (VPN) capability that allows partners and collaborators to use their existing Internet connections to access the Laboratory's resources securely over the Internet. Other cyber-related technological enhancements will be installed; these include a network perimeter (firewall), other secure remote access tools, and internal information aggregation.

Employees and subcontractors who send or personally carry computer hardware and software outside the United States must follow requirements in accordance with U.S. export control laws and regulations. The Contracts Division within the ORNL Business and Information Services Directorate provides guidance and assistance in export compliance.

7.2.3.5 • Foreign National Visits and Assignments

The ORNL Security Department manages the Laboratory's Foreign National Visits and Assignments (FNV&A) Program. The program, which is conducted in accordance with DOE Notice 142.1, "Unclassified Foreign National Visits and Assignments Program," July 14, 1999, and DOE Notice 205.2, "Foreign National Access to DOE Cyber Systems," November 1, 1999, is applicable whenever a "presence" at the Laboratory is requested for a foreign national. All requests for foreign national visits or guest assignments to the Laboratory are processed through the automated Non-Employee Processing System. This system is used to ensure proper submittal and tracking of requests, the completion of all requisite actions associated with the visit and/or assignment, and the completion of a formal concurrence process involving representatives from ORNL's Counterintelligence, Cyber and Physical Security, Export Compliance, and Technical Information and Classification Offices.

Integrated within this formal approval process are a requirement for visit and/or assignment hosts to receive recurring training from the Office of Counterintelligence (see Sect. 7.2.3.1), a requirement for hosts to formally acknowledge personal acceptance of responsibility for adherence to an applicable security plan for the visit or assignment, and, when necessary (e.g., for visitors or assignees from sensitive countries), documentation of assurance that a required Indices Check has been completed. Only when all requisite actions have been completed is visit or assignment approval referred to the Laboratory Director or authorized delegates for approval. Also, when questions or issues arise with respect to a particular visit or assignment, the Laboratory's Non-Citizen Access Review Committee is convened to evaluate issues and to make a final recommendation to the authorized approval authority on whether (1) the visit or assignment should be allowed to proceed, (2) supplementary security measures should be applied, or (3) the visit or assignment should be denied.

7.2.4 • Information Resource Management

ORNL is committed to managing and using its technical and administrative information as both an institutional and a multinational asset. The Laboratory's Chief Information Officer (CIO) is dedicated to creating an environment in which access to and use of information is a nonintrusive enabler of achieving the R&D missions of ORNL while protecting valuable assets.

Core information management and information technology services are provided by the ORNL Computing, Information, and Networking Division, which is led by the ORNL CIO. This organization coordinates with the Instrumentation and Controls Division to provide the strategic framework for information resource management for the Laboratory and with the ORNL Security Department to ensure information security (see Sect. 7.2.3.3) and cyber security (see Sect. 7.2.3.4). Outsourcing has been used to augment services and to provide access to capabilities not available at ORNL.

ORNL uses its information management expertise and extensive investments in computing and networking technology to enable the conduct of R&D. The Information Infrastructure Strategic Plan (Rev. 1) identifies five major focus areas that require strategic planning to meet the needs of ORNL staff in the future:

- Mobility/universal access—telecommuting, remote research, etc.
- Collaborative environment—multiprogram and multidisciplinary projects
- Transparency to the enterprise—nonemployee and interlaboratory access and support
- Intelligent tools for leveraging knowledge—improved interfaces and intelligent agents
- Integration of ORNL information enterprise—information architecture for more efficient use of systems

Implementation teams will develop roadmaps for achieving improved user experiences in all of these areas. Cost-benefit analyses will be performed to ensure that cost savings are a key driver in implementation.

Other priority activities include implementation of a managed hardware program and development of core software standards to strengthen management support for information as a corporate asset. The managed hardware program will provide staff members with an efficient and cost-effective way to acquire or upgrade to desktop computing resources that are preconfigured with the Laboratory's standard tools.

The World Wide Web is the interface of choice for the Laboratory's internal administrative information and business applications. The Web is the preferred interface for all strategic business applications. Information is distributed to staff through the Web, and most business processes have Web interfaces for staff input.

The growth and popularity of the Internet have allowed ORNL to share more information than ever before with a global audience. The ORNL public Web site provides a means for the public to submit information, make comments, and request information. Web servers are becoming the principal distribution point for information products from ORNL's information centers and databases.

Web access to key electronic information sources maximizes the availability of information to ORNL staff. Enhanced access to such information has been effected by a consortium of libraries at DOE laboratories. The Laboratory's Research Libraries are adding half a million dollars worth of electronic journals, at no additional cost to ORNL, effectively tripling the size of the electronic journal collection.

7.2.4.1 • Scientific and Technical Information

Scientific and technical information (STI) is a primary product of ORNL's R&D efforts. Unless specified otherwise by the sponsor, ORNL research activities culminate in STI that is shared with researchers and the general public worldwide. Many of these publications are forwarded to DOE's Office of Scientific and Technical Information (OSTI), where they are made available for downloading on the Information Bridge (http://www.doe.gov/bridge). ORNL is now using an electronic document clearance process that enables documents to go electronically from the author's desktop into DOE's Information

Bridge. Beginning in January 2001, all of ORNL's submissions to OSTI will be electronic. In addition, much of the Laboratory's STI is now available through internal and external Web sites.

ORNL is home to one of the most extensive and authoritative complexes of scientific data and information analysis centers in the United States, with several information analysis centers and more than 200 textual and/or numeric databases that cover various technical disciplines in support of DOE and other customers (e.g., the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, the Department of Health and Human Services). ORNL expects to continue its work to support national needs for scientific and technical information. Programs will be structured to take advantage of emerging information management technologies.

7.2.4.2 • Administrative Information

Most of ORNL's core business applications—including most aspects of payroll, benefits, and human resources—are handled by a single business software system, SAP R/3 (see Sect. 7.2.5). Studies continue to evaluate implementation of additional functions supported by the SAP software suite. Internal and external interfaces are also being evaluated for replacement or elimination.

ORNL and Lockheed Martin Energy Systems, Inc., the M&O contractor for the Oak Ridge Y-12 Plant, previously shared several business systems (software, hardware, and related data). More than 90 shared systems were separated before April 1, 2000, and ORNL is aggressively separating the remaining non-SAP systems, creating an independent systems environment for the first time. This will become the baseline for all future activities.

ORNL continues to improve employee access to information needed in the daily conduct of operations. Web technologies are applied to increase desktop access to information, with an emphasis on reducing costs and increasing end-user efficiency. Activities include

- using the Web as the preferred interface for forms and business applications;
- supporting Windows, MacOS, and UNIX client platforms;
- evaluating and implementing new applications through the Operational Software Review Board;
- upgrading operating systems and telecommunications; and
- initiating a managed hardware program.

7.2.5 • Business Management

ORNL is dedicated to continuously improving its management practices and operations, making it a more effective and efficient organization that is prepared to meet future operational challenges. Recent realignment and flattening of the business management organization provides more comprehensive financial expertise and support to all Level 1 managers. This reorganization removed a level of management and streamlined accounting and budgeting functions. The UT-Battelle Leadership Team addresses decisions affecting the Laboratory to ensure that business decisions enhance and support the future direction of the Laboratory. All Laboratory-level financial decisions are reviewed and approved by the Leadership Team prior to implementation.

Our Maximizing Research Effectiveness Initiative enlists all staff in a commitment to achieve indirect cost reductions that will deliver more R&D per dollar spent and provide more resources for discretionary investments in capability development and infrastructure revitalization. ORNL is committed to achieving a composite multiplier of 1.7 by the end of FY 2003. Business management processes (travel, payroll, procurement, etc.) will be evaluated for possible process improvements and cost efficiencies. ORNL will also implement an integrated planning and budgeting process that ensures a structured, disciplined process for the allocation of the Laboratory's discretionary resources.

ORNL continues to optimize the SAP R/3 enterprise information system. SAP R/3 is a fully integrated information system that eliminates the need to maintain and update multiple databases, thus reducing the costs required to maintain a number of nonintegrated business systems. SAP also supports all client platforms (Windows, Mac, UNIX) and provides aggressive Web interface strategy. ORNL's SAP system was developed in collaboration with Lockheed Martin Energy Systems, Inc., and certain elements of the system were shared by the two organizations. The ORNL system is now functioning as a completely separate information system.

ORNL is providing additional enhancements (e.g., custom reports) to the current SAP system in an effort to further meet the needs of end users. Basic cost and procurement data are being added to the SAP Web application to improve employee access to information. Additional systems and processes (such as travel; the Internal Approval Level process; and the Payroll, Absence, and Labor System) are currently being evaluated and may be absorbed into SAP in the future.

7.3 • Site and Facilities Management

ORNL is committed to good stewardship of its resources, both in management of existing facilities and in planning for future needs. In addition to management and maintenance of buildings and facilities at the main Laboratory site, UT-Battelle is responsible for (1) site and facility planning for ORNL and (2) management and planning for most of the undeveloped land area of the ~14,000-ha (34,424-acre) Oak Ridge Reservation.

Programs at ORNL require a variety of buildings and equipment, including specialized experimental laboratories, a large complement of office space, and major utility and waste disposal facilities. ORNL has one of the oldest physical plants in the DOE laboratory system, and continuing efforts will be required during the planning period to renovate and rehabilitate general-purpose buildings and utility systems that have deteriorated owing to insufficient capital improvement funding for modernization and adaptation to changing program needs.

The UT-Battelle Leadership Team is undertaking the revitalization of the ORNL campus over the next 5 years. The scope of the revitalization effort includes the construction of new research and administration/support facilities, the renovation of existing facilities, and the consolidation of ORNL's work at the main Laboratory site in order to build an integrated research campus for the 21st century. This Facilities Modernization Initiative is a key element of the Laboratory Agenda (see Sect. 3.2).

The *ORNL Land and Facilities Plan* (updated annually; the current version is available on the World Wide Web at http://www.ornl.gov/~dmsi/landUse/plan.htm) provides information on land and facilities use and planning for the Laboratory. *Comprehensive Integrated Planning Process for the Oak Ridge Operations Sites* (ORNL/M-6717, September 1999; http://www.ornl.gov/~dmsi/cip/cip.htm) is a planning reference that identifies primary issues regarding major changes in land and facility use for three DOE sites, including the Oak Ridge Reservation. ORNL has also developed a *Strategic Facilities Plan* (ORNL/TM-2000/238) to support DOE-SC in preparation of an Infrastructure Needs Assessment Report to address the issue of modernizing its laboratories. These documents and the *Oak Ridge National Laboratory Facilities Revitalization Project—Project Management Plan* (ORNL/TM-2000/174) provide details on ORNL's plans.

7.3.1 • Laboratory Description

ORNL's main site encompasses approximately 450 ha (1,100 acres) in the Bethel and Melton valleys, approximately 16 km (10 miles) southwest of the center of the city of Oak Ridge, Tennessee, with additional facilities located on the adjacent Copper Ridge. ORNL also occupies space at the Y-12 National Security Complex (formerly the Oak Ridge Y-12 Plant) and leases some space off site.

The ORNL site has many functions and requirements similar to those of a small city. It is supported by a dedicated fire department, a medical center, a security force, and a steam plant. Amenities include 290 km (180 miles) of roads, 55 km (34 miles) of overhead power lines, 8,230 m (27,000 ft) of steam lines, 30,480 m (100,000 ft) of treated water piping, and ~90 ha (225 acres) of mowed grounds.

As indicated in Table 7.1, buildings at the Melton Valley and Bethel Valley sites and Copper Ridge comprise ~316,000 square meters (3.4 million gross square feet) of building space; at Y-12, ORNL use accounts for ~130,000 square meters (1.4 million gross square feet) of building space.

Facilities accepted into DOE's EM program and those that are part of the waste management systems managed by Bechtel Jacobs under the M&I contract have been transferred to Bechtel Jacobs to

Table 7.1
ORNL space distribution

Location	Buildings Number	Buildings Space, ft^2	Trailers Number	Trailers Space, ft^2	Total space, ft^2
ORNL main site					
UT-Battelle	296	2,912,870	52	46,243	2,959,113
Bechtel Jacobs	132	446,638	33	26,918	473,556
Subtotal, ORNL main site	428	3,359,508	85	73,161	3,432,669
ORNL off-site					
American Museum of Science and Energy	2	55,4000	—	—	55,400
Grand Junction, Colorado	—	—	4	9,960	9,960
Subtotal, ORNL off-site	2	55,4000	4	9,960	65,360
ORNL at Y-12	21	1,372,910	—	—	1,372,910
Leased off-site	5	163,572	—	—	163,572
Total	**456**	**4,951,390**	**89**	**83,121**	**5,034,511**

facilitate the accomplishment of contractual responsibilities. With the exception of these facilities, ORNL has full responsibility for its Bethel Valley and Melton Valley sites and surrounding areas. ORNL is also responsible for management of an 8,530-ha (21,076-acre) portion of the ~14,000-ha (34,424-acre) Oak Ridge Reservation, including ORNL facilities and most of the ~8,000-ha (~20,000-acre) Oak Ridge National Environmental Research Park. At the Y-12 National Security Complex, ORNL has responsibility for building maintenance and ESH&Q functions as approved by Memoranda of Understanding with Y-12.

Replacement plant value is presented in Table 7.2. The overall condition of the space is shown in Fig. 7.1, with details on use and condition of space in Fig. 7.2 and a summary of building age in Fig. 7.3.

7.3.2 • Trends

Trends in ORNL's site and facilities management and planning will reflect the aims of the Facilities Modernization Initiative: construction of new facilities, renovation and upgrading of existing facilities, disposition of excess facilities, and consolidation of operations at the main Laboratory site to establish an integrated research campus for the 21st century.

The Enhanced Operational Discipline Initiative will provide for more effective management of all Laboratory facilities. The space charge system will be used to promote more effective and efficient use of ORNL buildings and to provide a more equitable distribution of building maintenance costs.

Table 7.2
Estimated replacement plant value
(in millions of FY 1997 dollars)

Facility type	Replacement cost
Buildings and structures	3,507
Utility systems	650
All other	300
Total	**4,457**

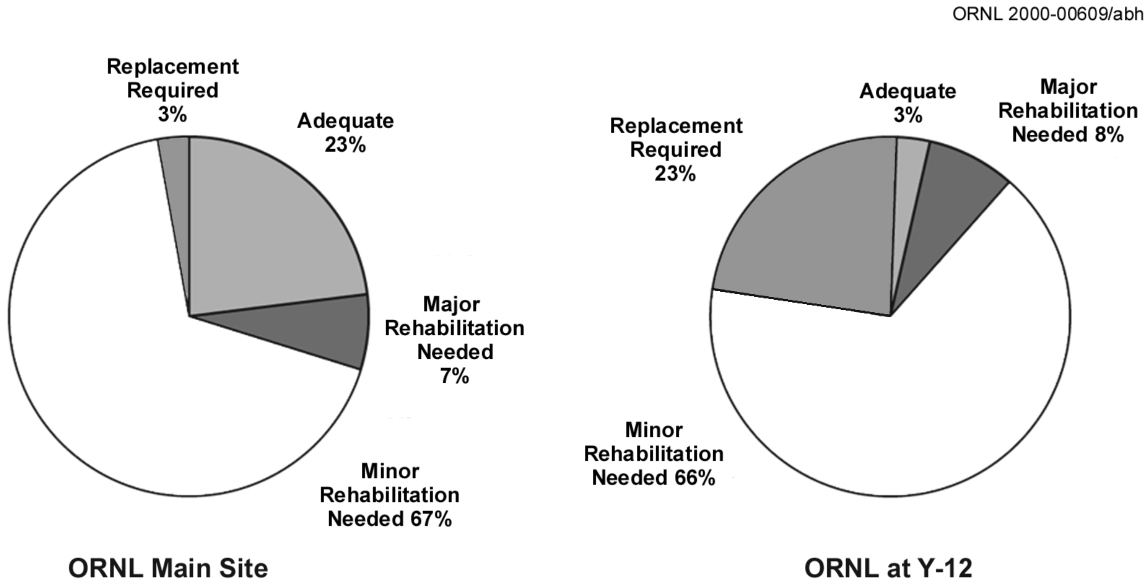

Figure 7.1
Condition of ORNL space at main ORNL site (left) and at Y-12 (right), based on cost of modification or repair as a percentage of replacement value. Adequate: cost < 10%. Minor rehabilitation: cost 10% to 25%. Major rehabilitation: cost >25% to 60%. Replacement: cost > 60%.

The transfer of contaminated facilities to the EM program will continue to reduce the amount of square footage and the number of buildings for which UT-Battelle is responsible. As plans for consolidation of operations at ORNL proceed, the number of ORNL staff housed at the Y-12 National Security Complex will decline.

Five facilities at Y-12 that were formerly occupied by ORNL staff, primarily in the Biology Complex, have been completely vacated. The bulk of the facility space (more than 357,000 square feet) is not contaminated and is not, therefore, a candidate for transfer to the EM program. It will be managed as landlord facilities until final disposition is determined. The remainder of the Biology Complex facilities, approximately 80,000 square feet, will be vacated by FY 2004 following construction of the new Laboratory for Comparative and Functional Genomics at ORNL (see Sect. 4.2.5). During FY 1999, six contaminated facilities and eight noncontaminated facilities were added to the surplus facility list, and three office trailers totaling approximately 3000 square feet were removed. New facilities added in FY 1999 include the High Flux Isotope Reactor (HFIR) Cold Source Building, the HFIR Neutron Sciences Support Building, and the Boiler No. 6 Addition at Building 2519.

7.3.3 • Site and Facilities Plans

7.3.3.1 • Facilities Modernization

ORNL has established a dedicated project team, the Facilities Revitalization Project (FRP), to carry out the task of providing ORNL staff with world-class facilities, consolidated at the main Laboratory site, with the first phase of construction to be completed within five years. The project will use a combination of DOE, state of Tennessee, and private-sector funds to accomplish this task.

A project management plan has been developed to provide the framework for conducting the FRP. The FRP is managed as a programmatic office, with primary resources for execution of the project to be obtained from the responsible organizations within ORNL (Engineering, Procurement, Strategic Planning, etc.). The project management plan includes a definition of the project scope, the organizational responsibilities, and the project approach, including a detailed Work Breakdown Structure (WBS)

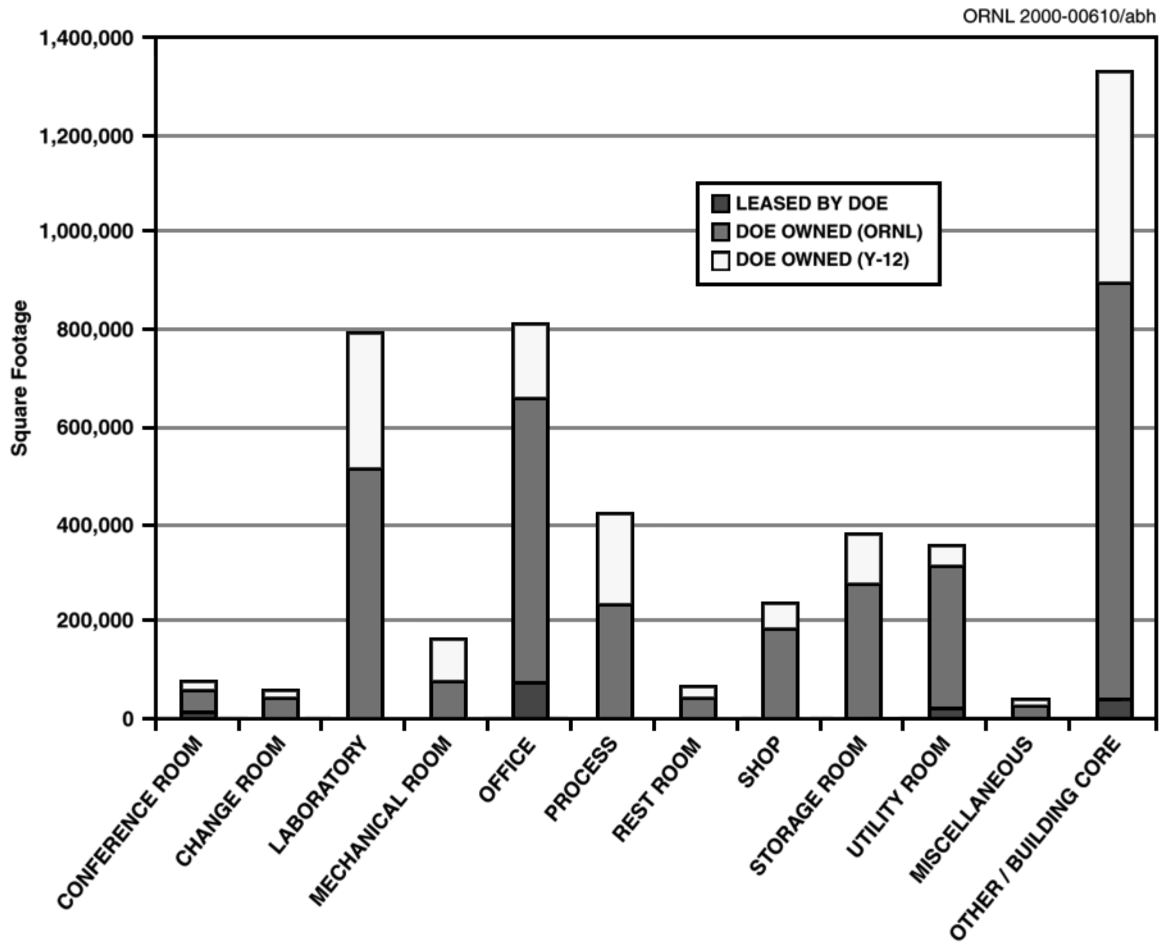

Figure 7.2
Ownership and use of ORNL space.

with three main elements: project planning basis, facility deactivation and consolidation, and new facilities development. FRP responsibilities include

- preparing an ORNL *Strategic Facilities Plan* that outlines the overall approach of the facilities development and reuse strategy and defines the unifying architectural and best energy management practices for the new facilities;
- developing and implementing an exit strategy for nonstrategic ORNL facilities, placing those facilities in a "cheap-to-keep" mode, and transferring those facilities to the appropriate DOE program for final disposition;
- constructing new facilities that leverage investments from DOE and the state of Tennessee; and
- acquiring new facilities through innovative approaches, using private-sector funding for construction, followed by ORNL leasing of that new space.

The overall approach to project execution is to apply a structured, but graded, process to the two major components of the FRP: consolidation of existing facilities and construction of new facilities. Current approved policies and procedures will be applied for the DOE-funded portions of the project (both facility transfers and capital construction) with modifications of those processes implemented for the private-sector and state of Tennessee–financed facilities improvements, as appropriate.

As part of the FRP, ORNL has developed a Master Plan for site development that supports the Laboratory's expected mission needs during the planning period; establishes a safe, high-quality, energy-efficient work environment for research and support staff in a research campus setting; and addresses the

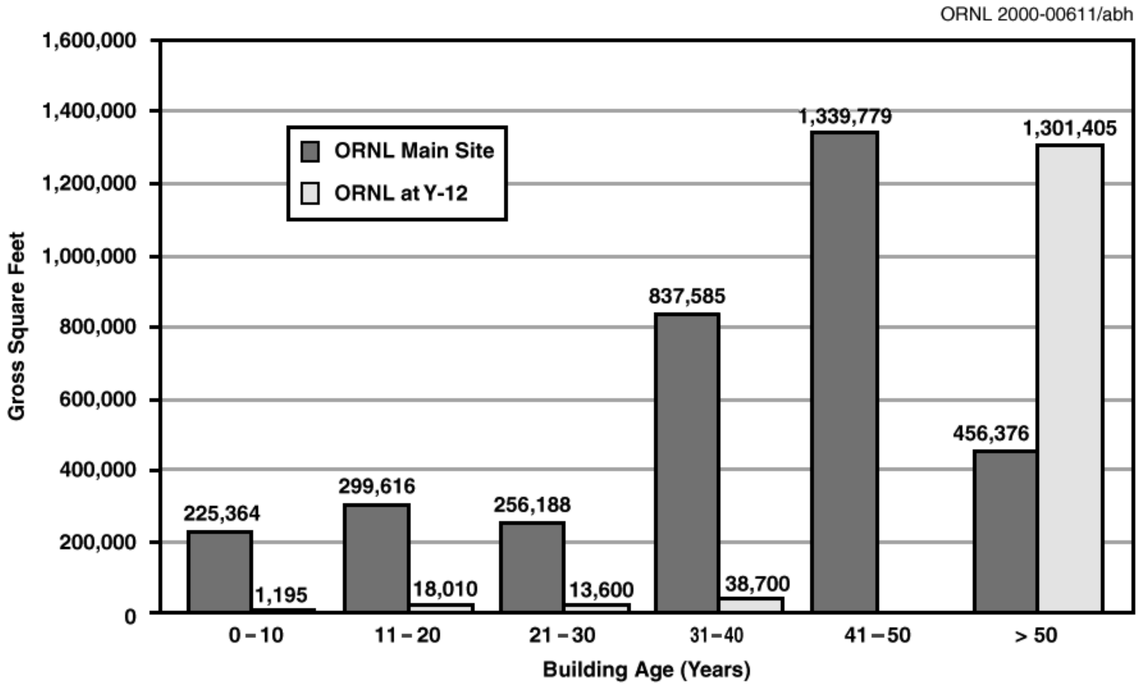

Figure 7.3
Age of ORNL buildings.

long-term maintenance and ultimate disposition of "retired" facilities in an environmentally acceptable manner. This plan will result in the consolidation of ORNL space from the current occupied levels of more than 4.5 million square feet to just over 3.2 million square feet, with the consolidated staff residing almost exclusively at the main ORNL site. The Master Plan outlines a phased approach to facilities modernization, with the primary emphasis during the planning period placed on establishing the East Campus infrastructure, constructing and refurbishing critical mission-oriented research facilities, and moving staff from the Y-12 Plant to the main ORNL site. The second phase would include completion of the East Campus core construction, continuing consolidation of off-site staff at the main ORNL site, and primary development of the ORNL West Campus for life and environmental sciences research.

Accomplishing the Facilities Modernization Initiative in the proposed time frame will require resources beyond those normally provided by DOE capital construction programs. Therefore, the integrated construction plan includes both private-sector funding and investments by the state of Tennessee in addition to available line-item and General Plant Project (GPP) funds. An upper-level schedule outlining the major construction activities to be conducted during implementation of the Master Plan is presented in Fig. 7.4. This schedule will be refined as funding profiles, project scope, and method of accomplishment are defined by DOE.

7.3.3.2 • Facilities Management

The Enhanced Operational Discipline Initiative includes the task of upgrading the Laboratory's infrastructure and providing effective stewardship of facilities and operations resources. We have initiated the development of a management process to enhance research and support operations through facility use agreements (FUAs), building manager and facility core teams, and integrated operations. The system will define work processes and ownership, establish responsibilities and authorities, and develop continuous improvement targets for work processes.

To facilitate this initiative, FUAs will be developed and used to define the scope of work supported by each facility's design and operating boundaries, establish the service levels that can be expected by

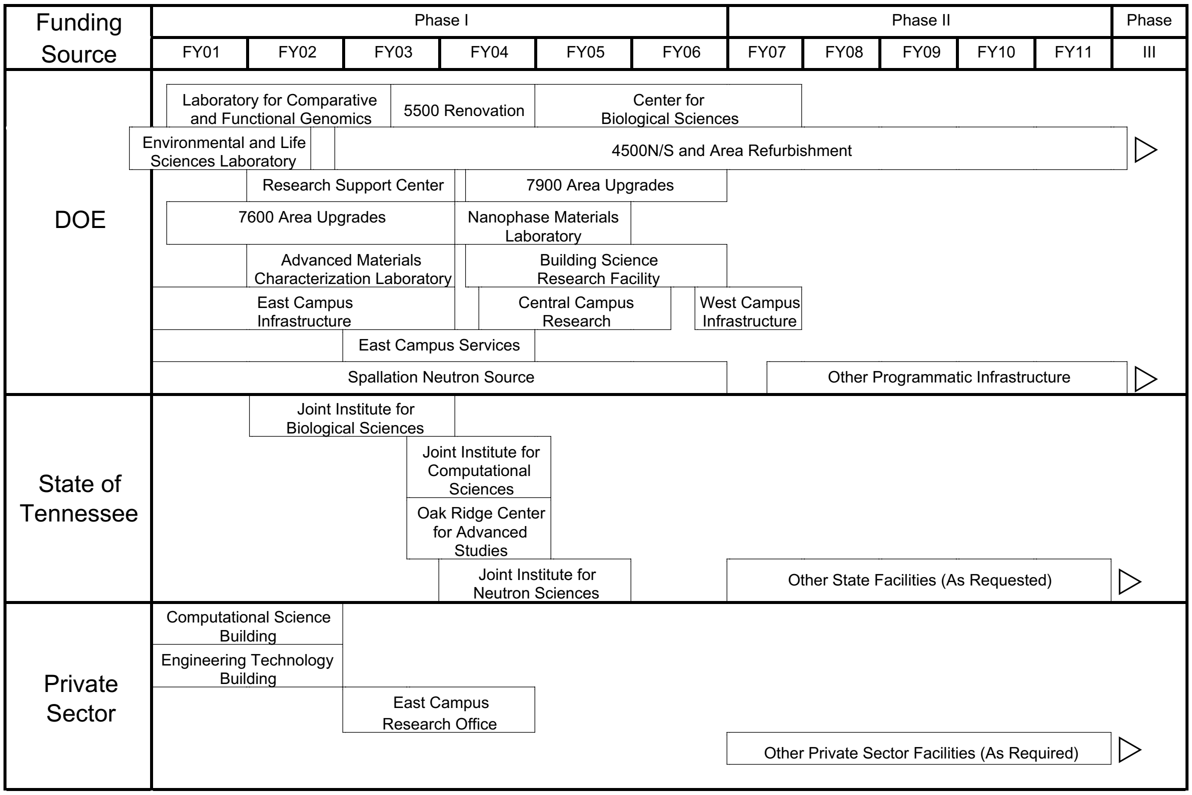

Figure 7.4
Preliminary schedule for ORNL site development.

occupants from building service providers, and link occupant work activities within the facility to applicable policies and procedures. The link between FUAs and work control establishes a documented basis for facility-level controls tailored to level of hazard and acceptable risk, provides a basis on which to evaluate the conduct of proposed activities in terms of the recognized building work scope and operating boundaries, and drives the implementation of a documented review and change control process when work activities have the potential to exceed the operating boundary. A facility management pilot project implemented in FY 2001 will provide input to the development of the facility management model and to the definition of the path forward.

7.3.4 • Detailed General-Purpose Facilities Plans and Facilities Resource Requirements

The key general-purpose facility issues at ORNL include (1) relocation of ORNL organizations at Y-12 to the main ORNL site, (2) upgrades and modifications to existing laboratory and experimental space to better facilitate R&D activities, (3) upgrades and replacement of site and facility utility systems, and (4) disposition of inactive/surplus facilities. These issues are being addressed through the Facilities Modernization Initiative and the Enhanced Operational Discipline Initiative (see Sect. 7.3.3).

Traditional funding sources for infrastructure modernization include GPP and general-purpose equipment (GPE) budgets, programmatic line items, and DOE's Multiprogram Energy Laboratory Facility Support (MEL-FS) Program. To meet ORNL's needs for modernization, innovative arrangements have been established to add funding from the state of Tennessee and the private sector funds to these sources.

Table 7.3 shows currently funded construction projects. The *ORNL Strategic Facilities Plan* provides a comprehensive list of proposed construction and renovation projects. A list of projects proposed for DOE capital funding to achieve DOE-SC's vision of a 21st Century Laboratory at ORNL is presented in Table 7.4.

Table 7.3
Major construction projects: funded construction[a]
($ in millions—BA)

	TEC[b]	Fiscal year 2000	2001	2002	2003
Research Program Line Item Projects					
Accelerator and Reactor Improvements and Modifications	6.90	2.80	1.80	0.40	—
Spallation Neutron Source	1,411.70	117.90	278.50	291.40	224.50
General Purpose Facility Line Item Projects					
Replace deteriorated roofing	15.00	0.75	—	—	—
Electrical systems upgrade	5.90	0.36	5.54		
Fire protection system upgrade	5.92	—	0.58	3.62	1.72
Laboratory facilities HVAC upgrades	7.10	—	0.50	3.00	3.60
General Plant Projects—Landlord					
Environmental and Life Sciences Laboratory	3.00	0.50			
7600 area office building	2.80	—	0.30	2.50	—
HFIR cooling tower replacement	4.80	1.80	3.00		
Building 7602 high bay upgrade	0.85	—	0.20	0.65	—
Lambert Quarry fencing	0.17	—	0.17	—	—
Fire protection upgrades	3.00	0.15	0.50	0.80	—
East campus infrastructure improvement projects	5.10	—	0.70	2.40	2.00
Replacement of No. 1 water reservoir	1.70	1.70			
Nanoscience Metrology and Instrumentation Laboratory	1.30	0.30	0.60	0.40	
Total funded construction	**1,475.24**	**126.26**	**292.39**	**305.17**	**231.82**

[a]Construction data as of October 2000.
[b]TEC = total estimated cost. May include funding from prior years.

7.3.5 • Space Management and Inactive Surplus Facilities

7.3.5.1 • Space Management

ORNL initiated a space charge system in FY 1998 to promote more effective and efficient use of ORNL buildings and to provide a more equitable distribution of the costs associated with maintaining these buildings. Space charge components include facility planning and administration, nonprogram line item/GPP construction design, space relocation (forced), lease costs, janitors, asbestos abatement (management), building maintenance/services, HVAC maintenance, grounds maintenance, utilities on returned space, activity data sheet (ADS) requirements, In-House Energy Management, and fire protection engineering. The Space Allocation Management System (SAMS), which contains data associating a specific employee and organization with occupied space, is used for allocation of space charges. The space charge system will continue to be refined to drive greater efficiency in the use of space, in support of the aims of the Enhancing Operational Discipline Initiative.

As a result of space charge implementation, approximately 400,000 square feet of marginal space has been vacated. Approximately 357,000 square feet of this space has been offered for reindustrialization. Four buildings, totaling 28,000 square feet, have been transferred to the Oak Ridge Y-12 Plant; 15,000 square feet is contaminated and will be proposed for inclusion in the EM program in FY 2002.

Table 7.4
DOE resources needed for achieving a "21st Century Laboratory"[a]
($ in millions—BA)

	TEC[b]	Fiscal year 2001	2002	2003	2004	2005
Programmatic Line Item Projects						
Laboratory for Comparative and Functional Genomics	13.9	2.5	10.0	1.4	—	—
Center for Nanophase Materials Science	20.0	—	—	2.0	14.0	4.0
Building Science Research Facility	20.0	—	—	—	2.0	14.0
Center for Biological Sciences	20.0	—	—	—	—	2.0
Landlord Line Item Projects						
Research Support Center	16.0	—	10.0	6.0	—	—
Laboratory upgrades and renovations, 4500 area	148.5	—	1.9	13.6	16.1	19.1
Other Line Item Projects	70.4	6.6	6.6	7.1	11.1	16.5
Programmatic General Plant Projects						
Cold Guide Hall Extension	3.0	2.2	0.8	—	—	—
HFIR User Support Facility	4.5	—	—	0.5	4.0	—
Landlord General Plant Projects						
Advanced Materials Characterization Laboratory	4.8	—	0.4	4.4	—	—
East Campus Service Building	4.4	—	—	0.4	4.0	
Central Campus Research Building	4.5	—	—	—	0.4	4.1
7600 Area Projects	11.2	0.5	3.7	4.5	2.5	—
7900 Area Projects	9.0	—	0.3	2.6	0.3	3.0
Building 5500	4.5	—	—	1.5	3.0	—
East Campus Infrastructure Projects	5.1	0.7	2.4	2.0	—	—
Utility Upgrades (GPP/GPE)	64.4	4.1	2.6	2.0	4.8	4.8
Other GPP/GPE	88.6	2.7	6.6	2.6	5.0	8.1
Project Starts after FY 2005	2.5	—	—	—	—	—
Total	515.3	19.3	45.3	50.6	67.2	75.6

[a]Source: Table 6.3 of *Oak Ridge National Laboratory Strategic Facilities Plan,* ORNL/TM-2000/238, October 2000 (available on line at http://www.ornl.gov/~dmsi/strategic_plan/index.html).
[b]TEC = total estimated cost.

7.3.5.2 • Facilities Consolidation and Deactivation

The FRP is responsible for developing and implementing an exit strategy for nonstrategic ORNL facilities; transferring nonstrategic, uneconomical, or underutilized facilities that no longer support the Laboratory's mission to other parties; and placing facilities that cannot be transferred in a "cheap-to-keep" mode (i.e., a state of minimum cost, with the minimum utilities, maintenance, and surveillance). These tasks are addressed in the FRP WBS by a Facility Consolidation and Deactivation Element.

The FRP has completed an inventory of existing facilities use and conditions and developed a list of nonstrategic facilities. Two disposition paths will be used to handle facilities determined to be surplus: facility transition and facility deactivation. Facilities on the transition path will be transferred to another contractor for alternate use or to an entity such as the Community Reuse Organization of East Tennessee (CROET). Facilities on the deactivation path will be placed in "cheap-to-keep" mode and put under a routine surveillance and maintenance (S&M) program. Those that meet the criteria for DOE's Environmental Management Program (DOE-EM) will be transferred to DOE-EM as soon as possible.

ORNL faces an enormous challenge in the deactivation and disposition of its nonstrategic facilities. Many of these facilities are large and complex, and some contain multiple hazards. The *ORNL Strategic Facilities Plan* lists 36 facilities (including 11 at Y-12), representing more than 1.1 million square feet, as candidates for disposition through DOE-EM, and 82 facilities, including a number of trailers, that would remain the responsibility of DOE-SC. The estimated cost of facilities consolidation and S&M during the time frame of the *ORNL Strategic Facilities Plan* (FY 2001–FY 2011) is $113 million. The estimated cost for ultimate D&D of ORNL's nonstrategic facilities is $126 million; under the present schedule, most D&D activities will be conducted after 2011.

7.3.6 • Energy Management

ORNL's In-House Energy Management (IHEM) program is directed toward saving energy, reducing energy costs, protecting the environment, enhancing the workplace environment, improving operations, and providing leadership in the adoption of new energy technologies. The program has yielded a 17% reduction in energy use per square foot of occupied space since 1985.

Several energy management initiatives are under way, and positive results are being realized. Key activities include the following:

- About 39,000 fluorescent lamps have been replaced with more efficient lamps; almost 21,000 ballasts have been replaced with more efficient units that do not contain polychlorinated biphenyls (PCBs); and about 900 occupancy sensors have been installed to switch off lights in empty rooms. Energy usage and costs have been reduced by 30 to 70% in the affected areas.
- ORNL continues to retire CFC chillers or replace them with high-efficiency, non-CFC chillers. To date, 16 chillers totaling 8,200 tons in cooling capacity have been replaced. As a result, chiller energy use has dropped an average of 21% for annual savings of $280,000, and CFC emissions have been cut by 5000 lb per year, saving another $76,000 annually.
- Energy management control systems have been installed in 13 buildings; this includes the installation of 19 variable-speed drives on supply and exhaust fan motors.

In addition, the conversion of the ORNL steam plant from coal to natural gas (see Sect. 7.3.2.4) is expected to save about $1 million per year in operating costs and $8 million in capital funding over 10 years, in addition to avoiding emissions from coal combustion.

ORNL is actively pursuing the completion of IHEM projects and continuing to take advantage of the savings from recently completed IHEM projects. Of 12 IHEM projects in construction at the start of FY 1999, all have been completed and closed out. Those completed projects, in combination with previous IHEM projects, have helped ORNL to minimize its energy consumption.

ORNL is also pursuing energy savings performance contracting (ESPC) as a way to implement projects using the funding and support of an energy service company (ESCO). When a project is complete, the ESCO is paid back from the energy savings. Once the ESCO is paid in full, the infrastructure improvements and future energy savings belong to ORNL. The first ESPC project is nearing the construction phase, and a second is in the development stages.

ORNL recently became the first industrial participant in the Green Power Switch program established by the Tennessee Valley Authority (TVA). The program offers power produced using renewable energy sources such as sunlight, wind, and landfill gas. Although this "green power" costs slightly more than power from traditional energy sources, it is expected to improve regional air and water quality by reducing waste and pollution. In addition, increased demand should lead to expanded power production capacity and eventually to lower costs.

8 • Community Service

UT-Battelle's commitment to excellence in community service includes three Laboratory-level initiatives (see Sect. 3.2) designed to broaden access to the extensive scientific and technological assets of the Oak Ridge National Laboratory (ORNL) and to leverage these resources to the benefit of the region. This commitment will be demonstrated through partnerships with the region's business community; schools, colleges, and universities; and economic development groups and through a public awareness program focused on local and regional stakeholders.

8.1 • Technology Transfer and Economic Development

Our Economic Development Initiative supports the creation and growth of businesses that will enhance the local economy by drawing on ORNL resources in knowledge and technology and on UT-Battelle investments in economic development.

The ORNL Technology Transfer and Economic Development organization, created in April 2000, comprises the Office of Technology Transfer and the Office of Economic Development.

8.1.1 • Technology Transfer

The Office of Technology Transfer is responsible for managing collaborations and access to ORNL resources and personnel through cooperative research and development agreements (CRADAs), technology licensing, and user facility programs. This office also manages and protects ORNL's intellectual property, leveraging this resource to increase its value through private-sector partnerships to promote the commercialization of innovations based on programmatic research and development (R&D) funded by the Department of Energy (DOE). More than 70% of this commercialization has been undertaken by small businesses. About one-third of the commercialization has resulted in the creation of start-up companies, more than 65% of which are located in East Tennessee.

CRADAs, licenses, and Work for Others (WFO) agreements are the main vehicles by which ORNL establishes partnerships with the private sector. These mechanisms enable transfer of Laboratory technology for commercialization and leverage DOE programmatic funding with funds in from the private sector. During FY 2000, 23 new CRADAs were established, 7 option agreements were executed, and 21 licenses were executed.

As DOE funding for CRADAs has decreased over the past five years, the number of private partners directly funding collaborative R&D has increased. Private-sector partners provide significant support to leverage programmatic funding for technology transfer, with more than $24 million in funds in to ORNL.

In August 2000, a CRADA was executed between ORNL and the United States Enrichment Corporation for the deployment of the next-generation centrifuge technology. Successful completion of this project could result in a new technology for enriching uranium. During the first year, this effort will bring $1,860,000 of privately sponsored research into the Laboratory, providing support for more than a dozen scientific staff members.

Some partnerships involve both licenses and CRADAs. ORNL's patented nonlinear condition monitoring technology has been licensed to Nicolet Biomedical, Inc., of Madison, Wisconsin, for application in a product to detect and predict the onset of epileptic seizures in humans. Under a related CRADA between ORNL and Nicolet Biomedical, researchers are developing a system that would provide an 8- to 50-minute warning before an epileptic seizure, giving a person time to take appropriate action. Graviton, Inc., of San Diego, California, has licensed microcantilever technology and radio-frequency wireless communications technology to produce sensors for use in drug discovery, clinical diagnostics, chemical detection, and physical sensing. Under a 100% funds-in CRADA, Graviton is expected to provide more than $4 million of R&D funding to ORNL over a period of three years. Graviton anticipates first sale of products under the licenses by January 2001.

User facility programs support access to ORNL's distinctive capabilities. User agreements between ORNL and outside organizations stipulate terms and conditions for use of the Laboratory's designated user facilities. More than 600 agreements are in place with universities, private companies, and other research institutions. In FY 2000, 50 new academic and industrial user agreements were signed, and 139 new projects were initiated under existing agreements.

Opportunities for industry have been expanded with the designation of the Laboratory's newest national user facility. The Advanced Propulsion Technology Center specializes in the detailed characterization of internal combustion engine emissions efficiency. This center does work for the DOE Office of Transportation Technologies in the Office of Energy Efficiency and Renewable Energy (DOE-EE), other federal agencies, and outside institutions. The facility's comprehensive capabilities include tabletop engine exhaust simulators, single and multicylinder engines and full vehicles. The center also houses several special diagnostic and measurement tools that aid in development and evaluation of engine and emission control technologies.

ORNL is an active partner in several consortia, including the Partnership for a New Generation of Vehicles (PNGV), which supports cooperative projects involving programs in DOE-EE, the DOE Office of Science, and the DOE Office of the Deputy Administrator for Defense Programs. ORNL is also pursuing the implementation of partnerships with companies and consortia representing the industries participating in the DOE-EE Industries of the Future initiative. In April 2000, ORNL signed a memorandum of understanding (MOU) with Secat, Inc., of Lexington, Kentucky. Secat is a University of Kentucky– affiliated, for-profit company that serves as a technical forum for the aluminum industry. The MOU establishes a vehicle to provide economic, environmental and energy benefits to the aluminum industry. The agreement also includes the Argonne National Laboratory and DOE's Albany Research Center.

Research staff members at ORNL generated 97 new invention disclosures, and the Office of Technology Transfer elected to request patent rights from DOE on 62 of these disclosures. The Office of Technology Transfer filed 71 patent applications during FY 2000.

8.1.2 • Economic Development

ORNL supports DOE's efforts to advance the nation's economic security by encouraging the use of DOE resources to address manufacturing problems and promote the creation of new businesses. In pursuit of this goal, the Laboratory is strengthening its partnerships with state and regional economic development groups.

- ORNL is promoting a broader program of technology transfer through the Center for Entrepreneurial Growth, a partnership with Technology 2020 of Oak Ridge.
- ORNL is broadening its role in industrial outreach through closer partnerships with the Tennessee Department of Economic and Community Development, Technology 2020, and the chambers of commerce in Oak Ridge, Anderson County, Roane County, and Knox County.
- ORNL's Small Business Program Office serves as the focal point for projects supporting minority businesses. Among these efforts is DOE's Mentor-Protégé Program.

Approximately $600,000 of UT-Battelle's annual corporate fee is directed to fund technology transfer, venture capital, and industry recruitment programs. In addition, UT-Battelle is promoting expanded corporate investment by providing access to a $100 million venture capital fund network to assist start-up companies.

DOE's Mentor-Protégé Program provides a mechanism for contractors to enter into integrated working relationships with and provide nonfinancial assistance to energy-related small, disadvantaged, and women-owned businesses to enhance their business and technical capabilities. In February 1998, ORNL became the first DOE national laboratory to participate in this program by signing a mentor-protégé agreement with Advanced Integrated Management Services, Inc. (AIMSI). Under the terms of the agreement, ORNL mentors AIMSI in a number of areas. Subcontracting activities are provided by ORNL's Chemical Technology and Engineering divisions for project management support. Training is provided as needed to enhance and strengthen AIMSI's technical and business capabilities.

UT-Battelle is also working to encourage more interaction with small businesses. Much of this activity is expected to occur in the technical assistance area, with support from DOE's Laboratory Technology Research assistance program.

The Small Business Program Office received an award from Secretary of Energy Bill Richardson for planning the first national DOE Small Business Conference, held in Denver in April 2000. More than 500 small businesses, 53 prime contractors, and 30 DOE programs and field offices were represented at the event. The ORNL team provided concept development, planning, coordination, logistics, and exhibit management.

8.2 • Education Partnerships

ORNL's education partnerships support DOE's commitment to effective programs for science education. The focus is on improving science and mathematics teaching skills and providing learning opportunities for faculty and students.

Through its Communications and Community Outreach (C&CO) directorate, ORNL coordinates a variety of programs that engage students and faculty in research, training, and collaboration. As these programs provide broad exposure to quality science and mathematics teaching and learning, they increase the number and diversity of high-achieving students introduced to research opportunities and potential careers at ORNL. Programs focus on inquiry-based, "hands-on" learning and research experiences that provide access to resources unavailable at many schools and universities.

Three new programs implemented in FY 2000 support our Science and Mathematics Education Initiative and are designed to identify ORNL closely with the emphasis, shared by DOE and the state of Tennessee, on improving mathematics and science learning among Tennessee students. Each year, UT-Battelle will provide five schools with state-of-the-art science laboratories. ORNL has also become the primary sponsor of the UT Academy for Teachers of Science and Mathematics, implementing a new emphasis on training larger numbers of Tennessee teachers. ORNL's participation in science and mathematics education is further strengthened through the underwriting of regional, state, and national high school competitions.

ORNL annually hosts several thousand students. Some participate in short programs, such as those available for K-12 students through the Ecological and Physical Sciences Study Center; others spend longer periods conducting research through programs such as the DOE Energy Research Laboratory Undergraduate Fellowships, the Great Lakes Colleges Association/Associated Colleges of the Midwest Oak Ridge Science Semester, or postdoctoral fellowships sponsored by ORNL or DOE.

Many of these activities are characterized by partnerships that extend beyond educational institutions, including

- the annual Women in Science and Technology Conference for high school and college students, co-sponsored by ORNL and DOE's Oak Ridge Institute for Science and Education;
- the annual summer SciCops camp, conducted in partnership with the Knox County Sheriff's Department, which introduces middle-school students to the role of science in law enforcement; and
- the Summer Science Honors Academy and Teacher Leadership Institute offered to students and teachers from Appalachian states through a partnership with the Appalachian Regional Commission.

Figure 8.1
Students visiting ORNL's Environmental Sciences Division.

8.2.1 • Pre-College Partnerships

In its K–12 education programs, ORNL emphasizes hands-on, engaged learning activities for both students and teachers. Programs are designed to develop scientific habits and help prepare students and teachers to be proactive in science, math, and technology education. Statistics on program participation are included in the Supplemental Information appended to this report.

The Ecological and Physical Sciences Study Center, one of ORNL's most visible activities, presents 33 instructional modules. Classes can be presented either at the historic Freels Bend cabin on the Oak Ridge Reservation or at schools or other locations. The Study Center now operates year-round, including summer science camps for middle school students and teacher workshops that transfer course content for classroom use. A continuing effort is made to reach students with physical and/or sensory disabilities. Classes and presentations are also offered to groups outside the academic arena (e.g., garden clubs, senior citizen groups, and Scouting groups).

A new program launched in FY 2000, ECOEDge, enables middle school and high school students to conduct research on parts of the Oak Ridge National Environmental Research Park.

8.2.2 • Higher Education Partnerships

In addition to the educational opportunities afforded by its research partnerships with universities (see Sect. 6), ORNL develops partnerships with colleges and universities that complement and extend the resources available in an academic setting. Statistics on program participation are included in the Supplemental Information appended to this report.

The UT-ORNL Graduate School in Genome Science and Technology offers a unique and multidisciplinary program for full-time graduate study leading to a Ph.D. or M.S. degree in this emerging field. The program takes advantage of interaction and collaboration among scientists at ORNL and faculty at UT, in conjunction with the Joint Institute of Biological Sciences (see Sect. 4.2.6). Courses and research opportunities are available at both locations, and research projects are mentored by a UT faculty member and an ORNL staff member. Other UT programs that draw on ORNL resources include the Graduate Program in Ecology and the Joint Program in Mixed-Signal VLSI and Monolithic Sensors. The UT Department of Physics and Astronomy also maintains close research relationships with ORNL; a new collaboration is creating enrichment materials in astronomy for use in K–12 classrooms.

ORNL is one of six multiprogram laboratories participating in the DOE Institute of Biotechnology, Environmental Science, and Computing for Community Colleges. The program provides educational training and research experience for highly motivated community colleges students through a summer institute for selected students.

ORNL is working to increase its interactions with historically black colleges and universities (HBCUs) and other 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. (GEM Consortium), the Consorcio Educativo para la Proteccion Ambiental (CEPA), and the Advanced Industrial Concepts Materials Fellowship Program. An August 2000 awareness meeting on current programs and activities with HBCUs and MEIs engaged the UT-Battelle Leadership Team, division directors, and diversity representatives in a discussion of how the Laboratory can develop an approach to strengthen future involvement. The meeting included a presentation on the HBCU/MEI Task Force created by the ORNL Leadership Action Consortium (see Sect. 7.2.2.4).

8.3 • Public Awareness and Community Outreach

ORNL's Community Involvement Initiative drives an outreach program guided by the desire to be viewed by our neighbors as a highly valued member of the community and the region. The program includes financial contributions to a variety of educational, civic, cultural, and economic development activities. In addition, the UT-Battelle Leadership Team participates in a number of volunteer activities and actively encourages the participation of Laboratory employees. Outreach initiatives, as well as issues affecting the Laboratory's scientific direction, are incorporated into a communications strategy for employees and external stakeholders. Communications activities are designed to provide a sense of inclusion to employees about the Laboratory's goals and activities. For external stakeholders, the goal is increased visibility and understanding of ORNL's mission, leading to a similar increase in public support for the Laboratory's role as a trusted regional asset.

8.3.1 • Outreach Activities

Community outreach activities provide opportunities to support DOE's commitment to building and maintaining public trust. Such activities also offer the chance to increase ORNL's visibility, broaden the understanding of the Laboratory's scientific programs and direction, and demonstrate ORNL's value to the community and the region. Many of ORNL's outreach activities are built around the themes of educational, civic, cultural, and economic development partnerships.

- Contributions from employees and UT-Battelle represent a large share of funds collected in the region's annual United Way campaigns. Many employees volunteer their time to United Way and to other charitable and civic programs.
- ORNL works closely with the American Museum of Science and Energy, providing financial and management assistance for a variety of educational and cultural programs at this important regional attraction.
- The ORNL Speakers Bureau provides opportunities for leading researchers to share information about DOE's missions with civic, educational and business groups throughout Tennessee.
- ORNL is a partner with DOE, Lockheed Martin, the National Park Service, and the Knoxville Convention and Visitors Bureau in the Gateway Regional Visitors Center on Knoxville's riverfront. ORNL communications staff provide support in developing exhibits for the center.
- UT-Battelle is a leading sponsor of civic and cultural activities in the Oak Ridge area, including the Oak Ridge Symphony and the Oak Ridge Arts Council, the League of Women Voters, and the National Association for the Advancement of Colored People.

ORNL's historic Graphite Reactor and the New Bethel Church Interpretive Center are open to the public seven days a week as part of a self-guided driving tour. Both facilities are featured on the Tennessee Heritage Trail listing developed by the state's Department of Tourist Development. ORNL C&CO staff helped initiate the use of the "Touch & Go" interactive information screens used at six Tennessee welcome centers to help inform travelers about ORNL visitor attractions. The Graphite Reactor hosted more than 9,100 visitors in FY 2000.

C&CO staff also provided 39 special orientation tours or customized tours for 1,293 visitors to the Laboratory and supported the Oak Ridge ORNL/Y-12 Plant Public Tour. This tour, which originates at the American Museum of Science and Energy in the city of Oak Ridge, is available from March through October. In FY 2000, it served 1,838 visitors. More than 12,000 visitors from all 50 states and 58 other nations have visited ORNL through the public tour, which is included on the Tennessee Heritage Trail.

These activities serve to educate local, regional and national groups about DOE activities in the Oak Ridge area. They are also expected to help increase science literacy and to provide feedback on how ORNL is perceived by the public.

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.

ORNL's scope of work includes the management of the American Museum of Science and Energy. The Laboratory works with DOE and Enterprise Advisory Systems, Inc., which operates the museum under subcontract to UT-Battelle, to strengthen public awareness of DOE programs and activities. The museum partnered with ORNL to offer several exhibits, including a September 1999 Technology Truck exhibit for 325 visitors, and support for special events, such as Chemistry Day (300 area students and teachers) and Space Day. A plan to ensure the financial stability of the museum will be completed early in FY 2001.

C&CO staff provide support and planning for community activities and special events. At ORNL, the Protocol Office hosted or provided support for visitors including Secretary of Energy Bill Richardson and staff members; DOE Under Secretary Ernest Moniz; Don Sundquist, Governor of Tennessee; and numerous other dignitaries.

A new visitor center has been established in Building 5002 to provide visitors to ORNL with an appropriate introduction to the Laboratory, its history, and its programs. C&CO staff worked with ORNL Graphics Services to plan and develop exhibits for the center. Plans are being made to broaden ORNL's community outreach activities and continue to improve the flow of information to employees.

8.3.2 • Communication Activities

UT-Battelle's efforts to have the public view ORNL as a highly valued asset include a variety of communication initiatives with internal and external stakeholders. The goal of the ORNL C&CO directorate is to provide stakeholders with a better understanding of what ORNL does and the positive impact of the Laboratory Agenda.

- The *ORNL Today* daily update on the Laboratory's internal Web server is viewed by employees more than 5,000 times each week.
- The *ORNL Reporter*, a newsletter that highlights Laboratory activities, is delivered monthly to employees and retirees and is available on the external Web server.
- The *ORNL Review*, an illustrated in-depth look at some of ORNL's efforts in scientific research, is published three times a year and distributed to employees and others with an interest in the Laboratory's activities. It is also available on the external Web server.

These communication vehicles, combined with all-hands meetings and a system of Laboratory-wide electronic mail, provide frequent, timely information about the nature and purpose of ORNL policies and programs.

As part of the April 2000 transition to UT-Battelle, increased emphasis was placed on communication with employees. Two all-hands meetings were held to provide an opportunity for Laboratory staff to meet the UT-Battelle management team and ask questions about the transition. These meetings were televised throughout ORNL via the in-house broadband network.

A brochure describing UT-Battelle's goals in science and technology, laboratory operations, and community service was mailed to all ORNL employees and to some 2,000 media outlets, business leaders, elected officials, and other stakeholders throughout Tennessee. Members of the UT-Battelle management team have also made a number of public appearances to communicate their goals and aims to the surrounding community.

The Laboratory's external relations program is designed to enhance ORNL's visibility among the public, media representatives, elected officials, and other stakeholders. Information about ORNL activities and their significance is provided to media representatives through the distribution of news releases, through telephone and face-to-face contacts made by ORNL C&CO staff, and through regular updates of ORNL's home page and news page on the World Wide Web. Awareness of ORNL and its missions is further enhanced in Knoxville, Nashville, and Chattanooga through the purchase of radio spots that reach an audience of approximately 130,000 persons.

More than 300 contacts with media representatives were made in FY 2000, and some 30 news releases were produced during this period. National and international media outlets publishing or broadcasting stories about ORNL included *Business Week, Chemical Engineering, National Geographic, USA TODAY,* the *New York Times,* the *London Mail,* the Associated Press, CNN, and National Public Radio.

9 • Resource Projections

Resource projections are presented in the following tables:

- Table 9.1, Laboratory funding summary,
- Table 9.2, Laboratory personnel summary,
- Table 9.3, funding by assistant secretarial level office, and
- Table 9.4, personnel by assistant secretarial level office.

These projections are based on funding requested in the FY 2001 budget submission documents, with some adjustments for subsequent guidance. They include some funding for construction that supports the major laboratory initiatives proposed in Sect. 4. In particular, capital equipment and construction funding estimates are provided for the Spallation Neutron Source (SNS).

In Tables 9.1 and 9.3, resource projections for future years are presented in terms of new budget authority (BA) funding in millions of dollars. New BA requests are calculated by adding estimates of fiscal year-end outstanding commitments (institutional, programmatic, and continued operation) to the total cost and then subtracting the prior-year uncosted budget.

Personnel projections in Tables 9.2 and 9.4 are given as the number of full-time equivalent (FTE) employees.

Additional detail is provided in the Supplemental Information appended to this report.

Table 9.1

Laboratory funding summary by fiscal year

($ in millions—BA)

	1999	2000	2001	2002	2003	2004	2005
DOE effort	546.4	461.5	493.8	473.1	477.5	490.5	513.0
Work for others	75.4	80.1	79.5	79.8	79.8	79.8	79.8
Total operating	621.8	541.6	573.3	552.9	557.3	570.3	592.8
Capital equipment (excluding SNS)	17.4	16.0	15.4	8.1	8.8	8.0	8.0
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Capital equipment, Landlord GPE[a]	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Construction (excluding SNS)	7.6	3.9	6.1	1.0	0.4	0.4	0.4
Construction, Landlord GPP[b]	4.4	4.5	6.3	5.7	5.7	5.7	5.7
SNS construction	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Total ORNL	756.5	669.5	862.4	851.2	789.1	711.3	689.0
Proposed construction	—	—	2.5	28.5	26.4	19.1	21.0
Total projected funding			864.9	879.7	815.5	730.4	710.0

[a]GPE = General Plant Equipment.
[b]GPP = General Plant Project.

Table 9.2

Laboratory personnel summary by fiscal year

[Full-time equivalent (FTE) employees]

	1999	2000	2001	2002	2003	2004	2005
Technical personnel, direct DOE effort	1495.3	1659.1	1665.9	1630.0	1630.0	1630.0	1630.0
Technical personnel, Work for Others	270.7	264.8	278.8	287.6	287.6	287.6	287.6
Total technical direct personnel	1766.0	1923.9	1944.7	1917.6	1917.6	1917.6	1917.6
Other direct	586.8	452.5	390.8	397.5	397.5	397.5	397.5
Total direct personnel	2352.8	2376.4	2335.5	2315.1	2315.1	2315.1	2315.1
Indirect personnel (estimated)	1940.2	1753.6	1564.5	1560.0	1560.0	1560.0	1560.0
Total ORNL personnel	4293.0	4130.0	3900.0	3875.1	3875.1	3875.1	3875.1

Table 9.3

Funding by assistant secretarial level office by fiscal year

($ in millions—BA)

	1999	2000	2001	2002	2003	2004	2005
Undersecretary for Energy, Science, and the Environment							
Office of Science							
Operating expense	173.0	173.1	169.5	162.0	163.6	174.2	190.4
Capital equipment	13.7	11.5	11.6	6.7	7.5	6.7	6.7
Capital equipment, Landlord GPE[a]	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Construction (excluding SNS)	9.6	3.9	6.1	1.0	0.4	0.4	0.4
Construction, Landlord GPP[b]	4.4	4.5	6.3	5.7	5.7	5.7	5.7
SNS construction	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Proposed construction	0.0	0.0	2.5	28.5	26.4	19.1	21.0
Total program	306.0	296.5	457.3	487.4	420.5	333.0	306.3
Office of Energy Efficiency and Renewable Energy							
Operating expense	105.9	110.1	127.0	132.2	137.5	143.0	148.6
Capital equipment	1.8	5.1	0.7	0.6	0.6	0.6	0.6
Total program	107.7	115.2	127.7	132.8	138.1	143.6	149.2
Office of Nuclear Energy, Science and Technology							
Operating expense	16.9	17.7	19.8	20.7	24.2	26.2	26.1
Capital equipment	0.0	(0.3)	0.0	0.1	0.1	0.1	0.1
Total program	16.9	17.4	19.8	20.8	24.3	26.3	26.2
Office of Fossil Energy							
Total operating	10.3	11.4	10.5	11.1	11.4	11.9	11.9
Energy Information Administration							
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Environmental Management							
Total operating	28.9	25.1	21.1	21.2	21.6	22.0	22.5
Capital equipment	1.9	(0.2)	0.2	0.2	0.2	0.2	0.2
Total program	30.8	24.9	21.3	21.4	21.8	22.2	22.7
Office of Civilian Radioactive Waste Management							
Total operating	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Undersecretary for National Nuclear Security							
Office of Defense Programs							
Total operating	20.1	18.6	20.8	21.3	21.6	21.9	22.2
Capital equipment	0.0	(0.1)	1.9	0.4	0.4	0.4	0.4
Construction	(2.0)	0.0	0.0	0.0	0.0	0.0	0.0
Total program	18.1	18.5	22.7	21.7	22.0	22.3	22.6
Office of Defense Nuclear Nonproliferation							
Total operating	20.2	10.7	35.9	30.3	31.4	30.3	30.1
Departmental Staff and Support Offices							
Office of Environment, Safety and Health							
Total operating	3.0	1.8	1.8	1.3	1.3	1.3	1.3
Office of Counterintelligence							
Total operating	1.4	1.8	1.3	1.4	1.4	1.4	1.4
Office of Security and Emergency Operations							
Total operating	0.0	0.1	5.9	5.9	6.1	6.3	6.5
Office of Policy							
Total operating	0.3	0.1	0.3	0.3	0.3	0.3	0.3

Table 9.3 (continued)
Funding by assistant secretarial level office by fiscal year
($ in millions—BA)

	1999	2000	2001	2002	2003	2004	2005
Office of Chief Financial Officer							
Total operating	1.5	0.4	(0.2)	0.0	0.0	0.0	0.0
Office of Worker and Community Transition							
Total operating	0.0	3.4	3.3	0.0	0.0	0.0	0.0
Federal Energy Regulatory Commission							
Total operating	0.5	0.1	1.2	1.2	1.2	1.2	1.2
Environmental Management (Bechtel Jacobs Company LLC)							
Total operating	65.4	26.1	14.0	7.7	4.4	4.0	4.0
Subtotal DOE Programs							
Total operating	447.7	401.0	432.7	417.0	426.4	444.4	466.9
Capital equipment (excluding SNS)	17.4	16.0	15.4	8.1	8.8	8.0	8.0
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Capital equipment, Landlord GPE	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Construction (excluding SNS)	7.6	3.9	6.1	1.0	0.4	0.4	0.4
Construction, Landlord GPP	4.4	4.5	6.3	5.7	5.7	5.7	5.7
SNS construction	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Proposed construction	0.0	0.0	2.5	28.5	26.4	19.1	21.0
Total	582.4	528.9	724.3	743.8	684.6	604.5	584.1
DOE Contractors and Operations Offices							
Total operating	94.6	53.5	55.0	50.0	45.0	40.0	40.0
Cooperative R&D Agreements							
Total operating	4.1	7.0	6.1	6.1	6.1	6.1	6.1
Total DOE Programs							
Total operating	546.4	461.5	493.8	473.1	477.5	490.5	513.0
Capital equipment (excluding SNS)	17.4	16.0	15.4	8.1	8.8	8.0	8.0
Capital equipment, Landlord GPE	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Construction (excluding SNS)	7.6	3.9	6.1	1.0	0.4	0.4	0.4
Construction, Landlord GPP	4.4	4.5	6.3	5.7	5.7	5.7	5.7
SNS construction	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Proposed construction	0.0	0.0	2.5	28.5	26.4	19.1	21.0
Total	681.1	589.4	785.4	799.9	735.7	650.6	630.2
Work for Others							
Nuclear Regulatory Commission							
Operating expense	9.7	8.1	7.5	7.0	7.0	7.0	7.0
Department of Defense							
Operating expense	26.5	33.5	32.5	29.3	29.3	29.3	29.3
National Aeronautics and Space Administration							
Operating expense	4.2	4.8	4.9	5.3	5.4	5.4	5.4
Department of Health and Human Services							
Operating expense	2.6	2.1	3.0	3.2	3.3	3.5	3.6
Environmental Protection Agency							
Operating expense	4.9	4.2	4.2	4.2	4.2	4.2	4.2
National Science Foundation							
Operating expense	0.6	0.0	0.0	0.0	0.0	0.0	0.0

Table 9.3 (continued)

Funding by assistant secretarial level office by fiscal year

($ in millions—BA)

	1999	2000	2001	2002	2003	2004	2005
Federal Emergency Management Agency							
Operating expense	2.0	0.4	0.5	0.5	0.5	0.5	0.5
Department of Transportation							
Operating expense	8.9	7.1	6.8	7.0	7.0	7.3	7.6
Other Federal agencies							
Operating expenses	0.1	4.9	5.3	8.5	8.3	7.8	7.4
Electric Power Research Institute							
Operating expense	0.8	1.0	0.1	0.1	0.1	0.1	0.1
Other nonfederal agencies							
Operating expense	15.1	14.0	14.7	14.7	14.7	14.7	14.7
Total Work for Others							
Operating expense	75.4	80.1	79.5	79.8	79.8	79.8	79.8
Total ORNL							
Operating expense	621.8	541.6	573.3	552.9	557.3	570.3	592.8
Capital equipment (excluding SNS)	17.4	16.0	15.4	8.1	8.8	8.0	8.0
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Capital equipment, Landlord GPE	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Construction (excluding SNS)	7.6	3.9	6.1	1.0	0.4	0.4	0.4
Construction, Landlord GPP	4.4	4.5	6.3	5.7	5.7	5.7	5.7
SNS construction	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Proposed construction	0.0	0.0	2.5	28.5	26.4	19.1	21.0
Total	756.5	669.5	864.9	879.7	815.5	730.4	710.0

[a]GPE = General Plant Equipment.
[b]GPP = General Plant Project.

Table 9.4
Personnel by assistant secretarial level office by fiscal year
[Full-time equivalent (FTE) employees]

	1999	2000	2001	2002	2003	2004	2005
Undersecretary for Energy, Science, and Environment							
Office of Science							
Technical personnel	540.5	662.4	722.7	701.2	701.2	701.2	701.2
Other direct personnel	174.9	254.1	219.1	223.4	223.4	223.4	223.4
Total direct personnel	715.4	916.5	941.8	924.6	924.6	924.6	924.6
Office of Energy Efficiency and Renewable Energy							
Technical personnel	233.9	291.9	281.8	282.5	282.5	282.5	282.5
Other direct personnel	33.8	41.2	46.3	44.1	44.1	44.1	44.1
Total direct personnel	267.7	333.1	328.1	326.6	326.6	326.6	326.6
Office of Nuclear Energy, Science and Technology							
Technical personnel	50.0	57.2	61.7	63.0	63.0	63.0	63.0
Other direct personnel	14.2	15.3	24.0	25.0	25.0	25.0	25.0
Total direct personnel	64.2	72.5	85.7	88.0	88.0	88.0	88.0
Office of Fossil Energy							
Technical personnel	20.1	26.7	25.5	23.6	23.6	23.6	23.6
Other direct personnel	6.1	4.2	4.1	3.7	3.7	3.7	3.7
Total direct personnel	26.2	30.9	29.6	27.3	27.3	27.3	27.3
Energy Information Administration							
Technical personnel	0.1	0.1	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
Total direct personnel	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Office of Environmental Management							
Technical personnel	94.7	93.2	86.6	86.3	86.3	86.3	86.3
Other direct personnel	15.0	18.0	12.9	11.7	11.7	11.7	11.7
Total direct personnel	109.7	111.2	99.5	98.0	98.0	98.0	98.0
Office of Civilian Radioactive Waste Management							
Technical personnel	0.1	0.5	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
Total direct personnel	0.1	0.5	0.4	0.4	0.4	0.4	0.4
Undersecretary for National Nuclear Security							
Deputy Administrator for Defense Programs							
Technical personnel	52.9	50.6	55.9	54.1	54.1	54.1	54.1
Other direct personnel	25.2	37.2	36.1	36.0	36.0	36.0	36.0
Total direct personnel	78.1	87.8	92.0	90.1	90.1	90.1	90.1
Deputy Administrator for Defense Nuclear Nonproliferation							
Technical personnel	46.5	41.8	42.1	40.1	40.1	40.1	40.1
Other direct personnel	4.1	4.3	3.8	3.8	3.8	3.8	3.8
Total direct personnel	50.6	46.1	45.9	43.9	43.9	43.9	43.9
Departmental Staff and Support Offices							
Office of Environment, Safety and Health							
Technical personnel	7.4	11.4	10.6	9.5	9.5	9.5	9.5
Other direct personnel	1.5	1.4	1.4	1.3	1.3	1.3	1.3
Total direct personnel	8.9	12.8	12.0	10.8	10.8	10.8	10.8

Table 9.4 (continued)

Personnel by assistant secretarial level office by fiscal year

[Full-time equivalent (FTE) employees]

	1999	2000	2001	2002	2003	2004	2005
Office of Counterintelligence							
Technical personnel	6.0	9.2	11.0	11.0	11.0	11.0	11.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	6.0	9.2	11.0	11.0	11.0	11.0	11.0
Office of Security and Emergency Operations							
Technical personnel	0.0	0.2	31.5	31.6	31.6	31.6	31.6
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.0	0.2	31.5	31.6	31.6	31.6	31.6
Office of Policy							
Technical personnel	1.3	3.0	2.7	2.7	2.7	2.7	2.7
Other direct personnel	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.9	3.0	2.7	2.7	2.7	2.7	2.7
Office of Chief Financial Officer							
Technical personnel	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
Total direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Worker and Community Transition							
Technical personnel	0.1	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
Total direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Federal Energy Regulatory Commission							
Technical personnel	2.8	5.7	3.0	2.9	2.9	2.9	2.9
Other direct personnel	0.3	1.6	0.8	0.7	0.7	0.7	0.7
Total direct personnel	3.1	7.3	3.8	3.6	3.6	3.6	3.6
Environmental Management (Bechtel Jacobs Company LLC)							
Technical personnel	99.6	118.3	90.1	92.3	92.3	92.3	92.3
Other direct personnel	234.2	11.5	7.9	5.7	5.7	5.7	5.7
Total direct personnel	333.8	129.8	98.0	98.0	98.0	98.0	98.0
Subtotal DOE Programs							
Technical personnel	1156.0	1372.2	1425.6	1401.2	1401.2	1401.2	1401.2
Other direct personnel	509.9	388.8	356.4	355.4	355.4	355.4	355.4
Total direct personnel	1665.9	1761.0	1782.0	1756.6	1756.6	1756.6	1756.6
DOE Contractors and Operations Office							
Technical personnel	330.6	270.2	224.7	222.7	222.7	222.7	222.7
Other direct personnel	24.2	26.4	12.0	8.4	8.4	8.4	8.4
Total direct personnel	354.8	296.6	236.7	231.1	231.1	231.1	231.1
Cooperative R&D Agreements							
Technical personnel	8.7	16.7	15.6	6.1	6.1	6.1	6.1
Other direct personnel	0.9	0.0	0.5	10.0	10.0	10.0	10.0
Total direct personnel	9.6	16.7	16.1	16.1	16.1	16.1	16.1
Total DOE Programs							
Technical personnel	1495.3	1659.1	1665.9	1630.0	1630.0	1630.0	1630.0
Other direct personnel	535.0	415.2	368.9	373.8	373.8	373.8	373.8
Total direct personnel	2030.3	2074.3	2034.8	2003.8	2003.8	2003.8	2003.8

Table 9.4 (continued)

Personnel by assistant secretarial level office by fiscal year

[Full-time equivalent (FTE) employees]

	1999	2000	2001	2002	2003	2004	2005
Work for Others							
Nuclear Regulatory Commission							
Technical personnel	43.2	38.1	35.7	34.0	34.0	34.0	34.0
Other direct personnel	6.5	4.9	2.3	1.3	1.3	1.3	1.3
Total direct personnel	49.7	43.0	38.0	35.3	35.3	35.3	35.3
Department of Defense							
Technical personnel	87.8	88.3	91.5	98.7	98.7	98.7	98.7
Other direct personnel	10.0	4.1	3.6	5.7	5.7	5.7	5.7
Total direct personnel	97.8	92.4	95.1	104.4	104.4	104.4	104.4
National Aeronautics and Space Administration							
Technical personnel	12.0	14.5	16.6	14.7	14.7	14.7	14.7
Other direct personnel	1.7	8.8	7.0	8.2	8.2	8.2	8.2
Total direct personnel	13.7	23.3	23.6	22.9	22.9	22.9	22.9
Department of Health and Human Services							
Technical personnel	11.5	8.3	7.2	2.0	2.0	2.0	2.0
Other direct personnel	16.0	2.5	3.0	1.0	1.0	1.0	1.0
Total direct personnel	27.5	10.8	10.2	3.0	3.0	3.0	3.0
Environmental Protection Agency							
Technical personnel	19.9	20.1	18.2	17.5	17.5	17.5	17.5
Other direct personnel	0.3	0.2	0.2	0.1	0.1	0.1	0.1
Total direct personnel	20.2	20.3	18.4	17.7	17.7	17.7	17.7
National Science Foundation							
Technical personnel	2.0	0.3	0.0	0.0	0.0	0.0	0.0
Other direct personnel	1.0	1.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	3.0	1.3	0.0	0.0	0.0	0.0	0.0
Federal Emergency Management Agency							
Technical personnel	5.5	4.5	3.4	3.3	3.3	3.3	3.3
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	5.5	4.5	3.4	3.3	3.3	3.3	3.3
Department of Transportation							
Technical personnel	23.5	27.6	16.4	14.2	14.2	14.2	14.2
Other direct personnel	3.0	0.0	0.0	2.8	2.8	2.8	2.8
Total direct personnel	26.5	27.6	16.4	17.0	17.0	17.0	17.0
Other Federal agencies							
Technical personnel	3.0	5.4	23.5	24.2	24.2	24.2	24.2
Other direct personnel	1.1	1.1	1.0	1.0	1.0	1.0	1.0
Total direct personnel	4.1	6.5	24.5	25.2	25.2	25.2	25.2
Electric Power Research Institute							
Technical personnel	6.0	2.3	0.7	0.2	0.2	0.2	0.2
Other direct personnel	1.0	0.7	0.0	0.0	0.0	0.0	0.0
Total direct personnel	7.0	3.0	0.7	0.2	0.2	0.2	0.2
Other nonfederal agencies							
Technical personnel	56.3	55.4	65.7	78.7	78.7	78.7	78.7
Other direct personnel	11.2	14.0	4.8	3.6	3.6	3.6	3.6
Total direct personnel	67.5	69.4	70.5	82.3	82.3	82.3	82.3

Table 9.4 (continued)

Personnel by assistant secretarial level office by fiscal year

[Full-time equivalent (FTE) employees]

	1999	2000	2001	2002	2003	2004	2005
Total Work for Others							
Technical personnel	270.7	264.8	278.8	287.6	287.6	287.6	287.6
Other direct personnel	51.8	37.3	21.9	23.7	23.7	23.7	23.7
Total direct personnel	322.5	302.1	300.7	311.3	311.3	311.3	311.3
Total ORNL							
Technical personnel	1766.0	1923.9	1944.7	1917.6	1917.6	1917.6	1917.6
Other direct personnel	586.8	452.5	390.8	397.5	397.5	397.5	397.5
Total direct personnel (FTE)	2352.8	2376.4	2335.5	2315.1	2315.1	2315.1	2315.1

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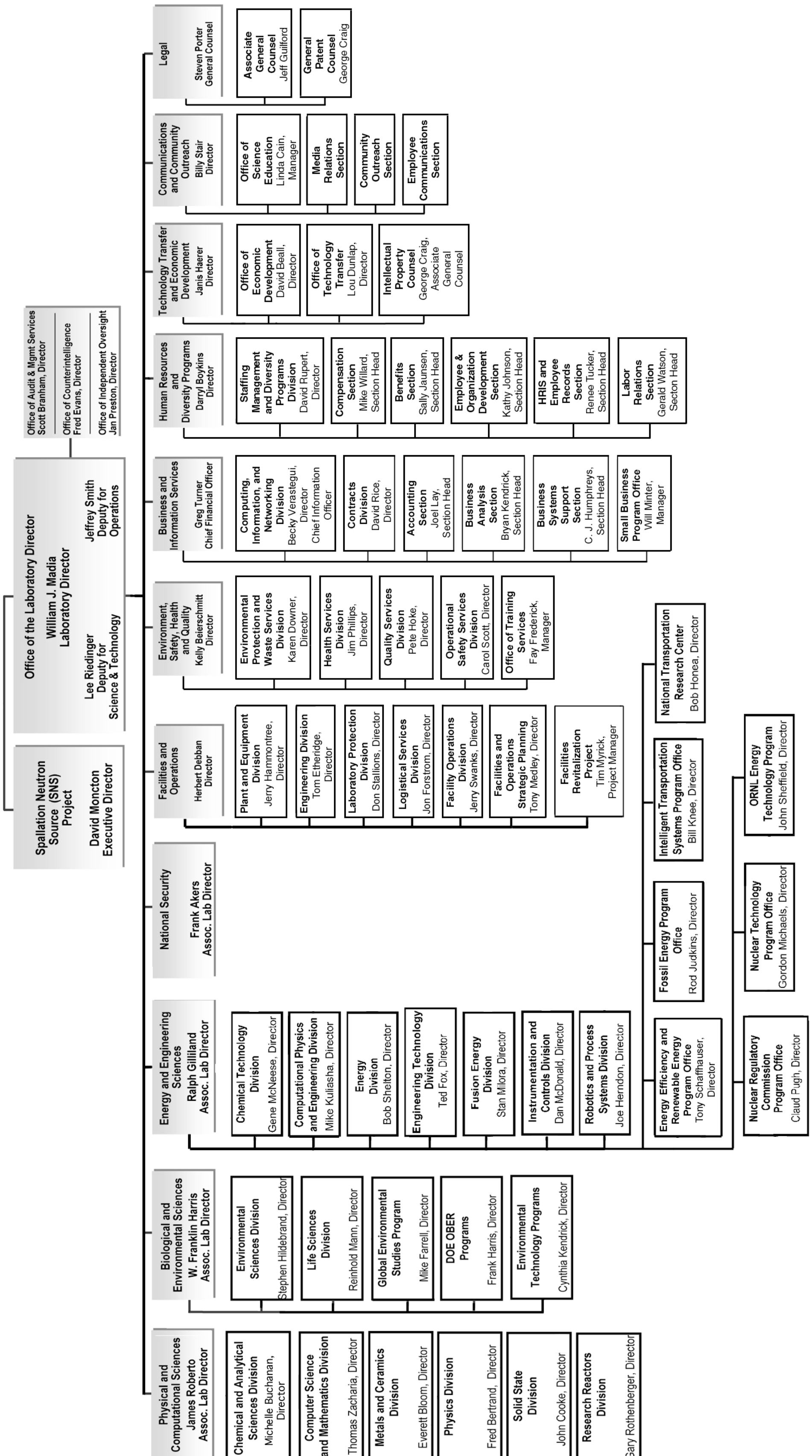
Supplemental Information


Spallation Neutron Source (SNS) Project
David Moncton Executive Director
Office of the Laboratory Director
William J. Madia Laboratory Director
Lee Riedinger Deputy for Science & Technology
Jeffrey Smith Deputy for Operations
Office of Audit & Mgmt Services Scott Branham, Director
Office of Counterintelligence Fred Evans, Director
Office of Independent Oversight Jan Preston, Director
Physical and Computational Sciences James Roberto Assoc. Lab Director
Chemical and Analytical Sciences Division Michelle Buchanan, Director
Computer Science and Mathematics Division Thomas Zacharia, Director
Metals and Ceramics Division Everett Bloom, Director
Physics Division Fred Bertrand, Director
Solid State Division John Cooke, Director
Research Reactors Division Gary Rothenberger, Director
Biological and Environmental Sciences W. Franklin Harris Assoc. Lab Director
Environmental Sciences Division Stephen Hildebrand, Director
Life Sciences Division Reinhold Mann, Director
Global Environmental Studies Program Mike Farrell, Director
DOE OBER Programs Frank Harris, Director
Environmental Technology Programs Cynthia Kendrick, Director
Energy and Engineering Sciences Ralph Gilliland Assoc. Lab Director
Chemical Technology Division Gene McNeese, Director
Computational Physics and Engineering Division Mike Kuliasha, Director
Energy Division Bob Shelton, Director
Engineering Technology Division Ted Fox, Director
Fusion Energy Division Stan Milora, Director
Instrumentation and Controls Division Dan McDonald, Director
Robotics and Process Systems Division Joe Herndon, Director
Energy Efficiency and Renewable Energy Program Office Tony Schaffhauser, Director
Fossil Energy Program Office Rod Judkins, Director
Intelligent Transportation Systems Program Office Bill Knee, Director
National Transportation Research Center Bob Honea, Director
Nuclear Regulatory Commission Program Office Claud Pugh, Director
Nuclear Technology Program Office Gordon Michaels, Director
ORNL Energy Technology Program John Sheffield, Director
National Security Frank Akers Assoc. Lab Director
Facilities and Operations Herbert Debban Director
Plant and Equipment Division Jerry Hammontree, Director
Engineering Division Tom Etheridge, Director
Laboratory Protection Division Don Stallions, Director
Logistical Services Division Jon Forstrom, Director
Facility Operations Division Jerry Swanks, Director
Facilities and Operations Strategic Planning Tony Medley, Director
Facilities Revitalization Project Tim Myrick, Project Manager
Environment, Safety, Health and Quality Kelly Beierschmitt Director
Environmental Protection and Waste Services Division Karen Downer, Director
Health Services Division Jim Phillips, Director
Quality Services Division Pete Hoke, Director
Operational Safety Services Division Carol Scott, Director
Office of Training Services Fay Frederick, Manager
Business and Information Services Greg Turner Chief Financial Officer
Computing, Information, and Networking Division Becky Verastegui, Director Chief Information Officer
Contracts Division David Rice, Director
Accounting Section Joel Lay, Section Head
Business Analysis Section Bryan Kendrick, Section Head
Business Systems Support Section C. J. Humphreys, Section Head
Small Business Program Office Will Minter, Manager
Human Resources and Diversity Programs Darryl Boykins Director
Staffing Management and Diversity Programs Division David Rupert, Director
Compensation Section Mike Willard, Section Head
Benefits Section Sally Jaunsen, Section Head
Employee & Organization Development Section Kathy Johnson, Section Head
HRIS and Employee Records Section Renee Tucker, Section Head
Labor Relations Section Gerald Watson, Secton Head
Technology Transfer and Economic Development Janis Haerer Director
Office of Economic Development David Beall, Director
Office of Technology Transfer Lou Dunlap, Director
Intellectual Property Counsel George Craig, Associate General Counsel
Communications and Community Outreach Billy Stair Director
Office of Science Education Linda Cain, Manager
Media Relations Section
Community Outreach Section
Employee Communications Section
Legal Steven Porter General Counsel
Associate General Counsel Jeff Guilford
General Patent Counsel George Craig

Work for Other Sponsors

Federal Organizations

Nuclear Regulatory Commission

ORNL supports the Nuclear Regulatory Commission (NRC) in nuclear safety, safeguards, and environmental protection activities and by providing a technical basis for the NRC's licensing and regulatory actions and decisions. Approximately 35 projects are administered through the NRC Programs Office; work is performed by 7 ORNL divisions and 2 Lockheed Martin Energy Systems, Inc., organizations. These projects are carried out in agreement with the Memorandum of Understanding established between DOE and NRC in 1978 and revised in 1998, and the work is conducted primarily for the NRC Offices of Nuclear Regulatory Research (RES), Nuclear Material Safety and Safeguards (NMSS), and Nuclear Reactor Regulation (NRR).

Research areas for RES include reactor pressure vessel (RPV) integrity (irradiation embrittlement, fracture mechanics assessment methodology, pressurized thermal-shock assessments, annealing studies, etc.), nuclear plant aging and license renewal issues, and instrumentation and controls technology. ORNL is a leader in the development and application of fracture mechanics technology for nuclear RPVs, in radiation experiments and embrittlement assessments, in boiling water reactor (BWR) core melt progression analysis, in testing techniques to assess component aging, and in microstructural examination methods. Some of this work is carried out in collaboration with other DOE laboratories and with researchers in other countries.

Another area of emphasis for RES is the collection, review, analysis, and evaluation of plant safety performance data. The Accident Sequence Precursor (ASP) program 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 the events. ORNL is assisting in the resolution of operational performance issues, benchmarking the operating records of 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 of reportable operational events at commercial nuclear power plants. This highly structured system, available to NRC staff via the World Wide Web, provides detailed searching of operational events. SCSS supports the ASP program, the NRC's Performance Indicator Program, quantification of common-cause failures, and hundreds of ad hoc queries each year from NRC staff. ORNL also supports the Performance Indicator Program by evaluating operational events to identify and document potential programmatic deficiencies and licensee corrective actions so as to readily ascertain adverse trends in performance.

Research areas for NMSS include criticality safety, shielding and thermal analyses of nuclear fuel facilities and cask designs, environmental review of licensee facilities, and review of terminated materials handling license files. The ORNL-developed computer code SCALE has been extended for NMSS use as this organization's reference code for criticality safety, shielding, and thermal analyses.

Technical assistance is provided to NRR in the areas of fuel stability analyses; economic analyses; component assessments; reviews of safety-related systems; nuclear plant license renewal issues; nuclear reactor licensing actions relative to design basis and severe reactor accident source terms; and fission product chemistry, iodine evolution and pH control.

U.S. Department of Defense

ORNL provides R&D support to the defense and national security community in areas where its capabilities are applicable to the mission of the Department of Defense (DOD) and related security agencies. Programs are conducted in close cooperation and coordination with BWXT Y-12, LLC, and other research partners and include basic and applied research, development, technology demonstration programs, and prototyping.

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. ORNL also performs research on advanced materials and processing for microelectronics.

Work continues to develop miniaturized sensors, intelligent sensors on a chip, and the latest generation of battlefield-portable mass spectrometers for point contact and stand-off detection of chemical and biological agents. New instrumentation, sensors, and data processing technologies are also being developed to improve detection of unexploded ordnance (UXO) and mines from land-, air-, and marine-based systems. This work is conducted in collaboration with DOD, academia, the private sector, and other DOE national laboratories.

Improved diagnostic and prognostic systems support the manufacture, life extension, and maintenance of weapon systems. Novel approaches to mobile communications and cyber security are being developed for the information assurance and protection of national security and business data and information. Joint Virtual Analysis Centers are being developed to collect, explore, and represent the information and knowledge contained in intelligence data sources. Common situational awareness tools are being developed to visualize the battle space for certain special military operations.

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. These efforts draw on ORNL capabilities in robotics and intelligent machines (see Sect. 5.3).

Work continues to develop the next generation of transportation and logistics models for defense customers, including transportation planning and tracking for rapid military response planning and execution for international contingencies. Novel applications of autonomous intelligent software are being developed to characterize, understand, and predict elements of the defense supply chain.

Environmental research is conducted for the Strategic Environmental R&D Program and the Environmental Security Technology Certification Program. These programs support the research, development, and evaluation of technology to better manage military base operations and 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.

National Aeronautics and Space Administration

ORNL serves as NASA's Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics for the Earth Observing System Data and Information System (EOSDIS). EOSDIS is part of NASA's contribution to the U.S. Global Change Research Program's effort to develop a predictive understanding of the global environment. Data from NASA and other sources archived at the ORNL DAAC are used to calibrate and verify remote sensing data and to parameterize and validate models of local, regional, and global-scale processes for projecting changes in the Earth's ecosystems. ORNL is a key site for NASA land validation activities. The Walker Branch Watershed on the Oak Ridge Reservation is one of the 24 core test sites selected to represent biomes globally. NASA selected the ORNL site because of the long history of these measurements coupled with extensive remote sensing data for the Oak Ridge Reservation. In order to promote the sharing of data and information, ORNL developed a modern Web-based system, Mercury <http://mercury.ornl.gov>, which assists investigators in documenting data and making them available to users throughout the world, regardless of discipline. ORNL is also supplying NASA with radio-frequency technology and expertise in high-temperature superconductors for an advanced rocket engine; assisting in data compilation on the growth of vegetation; and supporting NASA programs in aviation safety.

U.S. Department of Health and Human Services

The U.S. Department of Health and Human Services supports research in protein crystallography, bioanalytical chemistry, genetics, functional genomics, and toxicology through various institutes. Research into the genetics of obesity is supported through a grant from the National Institute for Diabetes and Digestive and Kidney Diseases. Investigations of the genetics of germ cell susceptibility to environmental mutagenesis are supported by an interagency agreement with the National Institute of Environmental Health Sciences. ORNL also conducts research for the National Cancer Institute; the National Heart, Lung, and Blood Institute; the National Institute on Aging; the National Institute Human Genome Research Institute; the National Institute for Mental Health; and the National Institute of General Medicine. Genetic, reproductive, and general toxicology databases are developed, analyzed, and evaluated for the Food and Drug Administration, the National Library of Medicine, and the National Toxicology Program, with support from the Environmental Protection Agency (EPA).

U.S. Environmental Protection Agency

ORNL's work for the EPA addresses numerous health and environmental problems and issues. Activities include evaluation of the cost-effectiveness of reducing nitrogen oxide emissions as a means of ozone control; involvement with EPA air quality research and modeling programs through NARSTO Quality Systems Science Center (a CDIAC program); activities in quality assurance and archiving of atmospheric chemistry and particulate matter data; support for ecological risk activities; guidance on indicators of landscape pattern and regional vulnerability studies of the biogeochemical cycling of mercury; collaboration with EPA scientists on the Design for the Environment Program; research on decentralized wastewater management concepts; evaluation of physiologically based pharmacokinetic models in risk assessment; continuing work on the Environmental Mutagen Information Center database; preparation of literature reviews and chemical hazard information profiles for selected topics and chemicals; maintenance of the Chemical Unit Record Estimates (CURE) database; field validation of analysis methods under the Environmental Technology Verification Program; and development of reference dose and reportable quantity profiles to reduce uncertainty in risk assessments.

National Science Foundation

The National Science Foundation (NSF) supports studies of nitrogen uptake, cycling, and retention in stream ecosystems using ^{15}N tracer addition experiments. The results will contribute to a better understanding of the mechanism responsible for and controls on ammonium and nitrate uptake and cycling and the effects of increased nitrogen inputs to streams. The NSF also supports free-air carbon dioxide enrichment (FACE) studies of a closed-canopy deciduous forest at the ORNL FACE Facility in the Oak Ridge National Environmental Research Park.

Federal Emergency Management Agency

ORNL programs for the Federal Emergency Management Agency include a range of R&D and technical assistance activities that support national preparedness for disasters and emergencies. ORNL serves as an independent center of expertise in areas that include engineering assistance, analysis and assessment, and emergency evacuation procedures.

U.S. Department of Transportation

ORNL assists the Department of Transportation's 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 also provides technical assessment of oil and gas pipeline systems throughout the United States for compliance with regulatory standards. This work is part of a broad transportation R&D and technology program (see Sect. 5.2.1).

Other Federal Agencies

ORNL provides technical support to a variety of other federal agencies, including the U.S. Department of Agriculture, the U.S. Department of Commerce, the U.S. Department of Education, the U.S. Department of the Interior, and the U.S. Department of State.

- The State Department provides support for work performed for the International Atomic Energy Agency and the United Nations Educational, Scientific, and Cultural Organization (UNESCO). ORNL assists the U.S. country studies program in support of the Intergovernmental Panel on Climate Change.
- Projects for the Department of Education include the development of a learning module to teach elementary physical principles as they apply to the construction and testing of a straw-bale wall and the design and programming of an automated decision-making software package for assessing data on secondary education schools and institutions.
- ORNL is collaborating with the U.S. Department of Agriculture (USDA) Office of Energy Policy and New Uses to incorporate data on potential energy crops into models of the agricultural sector used by USDA for economic and policy analyses. This work focuses on the FOLYSYS model developed and maintained for USDA by the University of Tennessee
- ORNL serves the U.S. Agency for International Development as a center of expertise on energy planning, policy development, and renewable energy applications. Activities include research; analysis; technical assistance; project development, implementation, and evaluation; and information dissemination.
- Support is provided to the Bureau of Labor Statistics in artificial intelligence systems to provide estimates of consumer prices index and survey automation.
- ORNL provides support in environmental management of water resources to several federal agencies. For example, ORNL staff serve as technical advisors to the U.S. Army Corps of Engineers on environmental issues such as hydropower impacts on fish and wildlife and instream flow policies and to the Northwest Power Planning Council and the Office of Science and Technology Policy on restoration of Pacific salmon.
- Under the sponsorship of the interagency Strategic Environmental R&D Program, ORNL staff are involved in an interagency group including DOE, DOD, 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. Ecological models developed at ORNL are used to address land management issues.

Nonfederal Organizations

ORNL performs research for and in collaboration with many nonfederal entities, both public and private. These efforts support DOE's aims in developing partnerships and applying the resources of the national laboratories to issues and problems of national importance.

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. This research includes evaluation of the ecological affects associated with water use for power generation; a project co-funded by DOE and EPRI to develop and demonstrate intelligent control systems for nuclear power plants; technology development in high-temperature structural design methods and fracture assessment procedures for advanced reactors and other high-temperature power plant components, the results of which support DOE's reactor programs; and physical chemistry studies related to power-plant steam cycles, which draw on fundamental work supported by the Office of Basic Energy Sciences in DOE's Office of Science.

Associated with EPRI research is work funded by Babcock and Wilcox (B&W) to develop a control algorithm that will be implemented by the B&W Owners Group on new digital control hardware.

Other Nonfederal Organizations

Private industry interacts with ORNL through cooperative R&D agreements, user agreements, licensing agreements, and other mechanisms. For example, ORNL supports the Idaho Power Company with environmental studies of how hydroelectric projects affect fish populations, an activity that complements other work for DOE's Hydropower Program. ORNL also interacts with many other nonfederal entities, including SEMATECH, the Japan Atomic Energy Research Institute, the Korea Atomic Energy Research Institute, the United Kingdom Atomic Energy Agency, the International Atomic Energy Agency, and Oak Ridge Associated Universities. States make use of ORNL expertise through agreements such as those with the State of Florida to study the environmental behavior of mercury; through the State Partnerships Program; and through user facility agreements, cooperative R&D agreements, and other mechanisms.

Supplemental Tables

Table S.1 presents projected resources (funding and direct personnel) by program. The projections in Table S.1 are based on funding requested in the FY 2001 budget submission documents, with some adjustments for subsequent guidance. The projections include some funding for construction that supports the major laboratory initiatives proposed in Sect. 4 of the Institutional Plan.

Resource projections for future years are presented in terms of new budget authority (BA) funding in millions of dollars. New BA requests are calculated by adding estimates of fiscal year-end outstanding commitments (institutional, programmatic, and continued operation) to the total cost and then subtracting the prior-year uncosted budget. Personnel projections are given as the number of full-time equivalent (FTE) employees.

Tables S.2 and S.3 present information about ORNL's staff. Table S.4 presents estimates for sub-contracting and procurement, reported as total obligated funds for each fiscal year, and Table S.5 presents estimates for small and disadvantaged business procurement.

Table S.6 provides details on the use of ORNL's designated user facilities during FY 1999. Table S.7 provides details on participants in ORNL's university and science education programs.

Table S.1
Resources by program by fiscal year
($ in millions)

	1999	2000	2001	2002	2003	2004	2005
Undersecretary for Energy, Science, and Environment							
Office of Science							
Magnetic Fusion—AT							
Total operating	17.8	18.2	16.5	16.3	16.3	16.3	16.3
Capital equipment	0.3	0.4	0.2	0.2	0.2	0.2	0.2
Total program	18.1	18.6	16.7	16.5	16.5	16.5	16.5
Total direct personnel (FTE)	70.6	62.9	58.9	61.5	61.5	61.5	61.5
High Energy Physics—KA							
Total operating	0.2	0.5	0.2	0.2	0.2	0.2	0.2
Capital equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	0.2	0.5	0.2	0.2	0.2	0.2	0.2
Total direct personnel (FTE)	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Nuclear Physics—KB							
Total operating	13.6	14.1	13.5	14.0	14.3	14.6	14.9
Capital equipment	2.1	1.7	2.0	2.0	2.0	1.5	1.5
Construction	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Total program	16.0	16.2	15.9	16.4	16.7	16.5	16.8
Total direct personnel (FTE)	69.1	66.4	61.4	58.1	58.1	58.1	58.1
Basic Energy Sciences—KC							
Operating expense (excluding SNS)	74.7	80.1	78.3	78.3	78.2	78.3	78.3
Operating expense, SNS	28.0	17.7	19.0	9.7	10.1	18.6	33.4
Total operating	102.7	97.8	97.3	88.0	88.3	96.9	111.7
Capital equipment (excluding SNS)	8.0	6.8	7.9	3.0	3.8	3.5	3.5
Capital equipment, GPE[a] Landlord	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Construction (excluding SNS)	2.5	2.4	4.6	0.6	0.0	0.0	0.0
Construction, GPP[b] Landlord	4.4	4.5	6.3	5.7	5.7	5.7	5.7
Construction, SNS	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Total program	222.9	215.0	377.4	380.8	314.7	233.0	203.0
Total direct personnel (FTE)	446.8	594.8	647.0	634.9	634.9	634.9	634.9
Energy Research Analyses—KD							
Total operating	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.3	0.2	0.0	0.0	0.0	0.0	0.0
Multiprogram Energy Laboratory—Facility Support—KG							
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Capital equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction, MGPF	6.8	1.1	1.1	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	1.0	18.5	25.0	19.1	21.0
Total program	6.8	1.1	1.1	18.5	25.0	19.1	21.0
Total direct personnel (FTE)	2.0	0.0	0.0	0.0	0.0	0.0	0.0
Computational and Technology Research—KJ							
Total operating	11.8	12.3	10.0	10.7	10.7	10.7	10.7
Capital equipment	1.5	0.1	1.0	1.0	1.0	1.0	1.0
Total program	13.3	12.4	11.0	11.7	11.7	11.7	11.7
Total direct personnel (FTE)	47.1	55.3	44.2	44.2	44.2	44.2	44.2

Table S.1
Resources by program by fiscal year (continued)
($ in millions)

	1999	2000	2001	2002	2003	2004	2005
Biological and Environmental Research—KP							
Total operating	26.2	29.2	31.4	32.2	33.2	34.9	36.0
Capital equipment	1.8	2.5	0.5	0.5	0.5	0.5	0.5
Proposed construction	0.0	0.0	2.5	10.0	1.4	0.0	0.0
Total program	28.0	31.7	34.4	42.7	35.1	35.4	36.5
Total direct personnel (FTE)	77.7	134.7	128.3	123.9	123.9	123.9	123.9
Office of Science Program Direction—KX							
Total operating	0.7	0.9	0.6	0.6	0.6	0.6	0.6
Total direct personnel (FTE)	0.5	0.9	0.7	0.7	0.7	0.7	0.7
Total Office of Science							
Operating expense	173.0	173.1	169.5	162.0	163.6	174.2	190.4
Capital equipment	13.7	11.5	11.6	6.7	7.5	6.7	6.7
Capital equipment, GPE Landlord	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Construction (excluding SNS)	9.6	3.9	6.1	1.0	0.4	0.4	0.4
Construction, GPP Landlord	4.4	4.5	6.3	5.7	5.7	5.7	5.7
SNS construction	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Proposed construction	0.0	0.0	2.5	28.5	26.4	19.1	21.0
Total program	306.0	296.5	457.3	487.4	420.5	333.0	306.3
Total direct personnel (FTE)	715.4	916.5	941.8	924.6	924.6	924.6	924.6
Office of Energy Efficiency and Renewable Energy							
Solar and Renewable Resource Technologies—EB							
Total operating	18.4	19.6	26.3	27.4	28.6	29.8	31.1
Capital equipment	0.5	0.3	0.1	0.1	0.1	0.1	0.1
Total program	18.9	19.9	26.4	27.5	28.7	29.9	31.2
Total direct personnel (FTE)	51.7	78.6	85.9	86.9	86.9	86.9	86.9
Buildings Sector—EC							
Total operating	19.5	19.3	24.1	24.6	25.0	25.5	25.9
Capital equipment	0.3	0.5	0.2	0.2	0.2	0.2	0.2
Total program	19.8	19.8	24.3	24.8	25.2	25.7	26.1
Total direct personnel (FTE)	52.2	58.2	48.2	50.2	50.2	50.2	50.2
Industrial Sector—ED							
Total operating	26.3	28.3	29.9	31.6	33.3	35.1	37.0
Total direct personnel (FTE)	58.1	70.5	63.0	52.3	52.3	52.3	52.3
Transportation Sector—EE							
Total operating	39.0	39.6	42.9	44.4	46.1	47.8	49.5
Capital equipment	1.0	3.9	0.3	0.3	0.3	0.3	0.3
Total program	40.0	43.5	43.2	44.7	46.4	48.1	49.8
Total direct personnel (FTE)	99.1	110.9	118.7	125.9	125.9	125.9	125.9
Policy and Management—EH							
Total operating	0.9	0.9	0.8	0.8	0.8	0.8	0.8
Total direct personnel (FTE)	2.2	2.2	2.2	1.7	1.7	1.7	1.7
Utility Sector—EK							
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Federal Energy Management Program—EL							
Total operating	1.8	2.6	3.1	3.4	3.7	4.0	4.3
Total direct personnel (FTE)	4.3	12.0	10.1	9.6	9.6	9.6	9.6

Table S.1
Resources by program by fiscal year (continued)
($ in millions)

	1999	2000	2001	2002	2003	2004	2005
In-House Energy Management—WB							
Total operating	0.0	(0.2)	(0.1)	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Total Office of Energy Efficiency and Renewable Energy							
Operating expense	105.9	110.1	127.0	132.2	137.5	143.0	148.6
Capital equipment	1.8	5.1	0.7	0.6	0.6	0.6	0.6
Total program	107.7	115.2	127.7	132.8	138.1	143.6	149.2
Total direct personnel (FTE)	267.7	333.1	328.1	326.6	326.6	326.6	326.6
Office of Nuclear Energy, Science, and Technology							
Nuclear Energy R&D—AF							
Total operating	5.5	5.2	6.6	8.4	11.9	13.9	13.8
Capital equipment	0.0	(0.1)	0.0	0.1	0.1	0.1	0.1
Total program	5.5	5.1	6.6	8.5	12.0	14.0	13.9
Total direct personnel (FTE)	17.6	24.6	31.1	35.1	35.1	35.1	35.1
Naval Reactors—AJ							
Total operating	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel (FTE)	0.4	0.5	0.4	0.4	0.4	0.4	0.4
Uranium Enrichment—CD							
Total operating	0.1	1.5	1.9	1.0	1.0	1.0	1.0
Total direct personnel (FTE)	1.1	3.4	4.5	3.2	3.2	3.2	3.2
Policy and Management—KK							
Total operating	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Total direct personnel (FTE)	0.0	0.7	1.2	1.0	1.0	1.0	1.0
Isotope Production and Distribution Program—ST							
Total operating	11.1	10.8	11.0	11.0	11.0	11.0	11.0
Capital equipment	0.0	(0.2)	0.0	0.0	0.0	0.0	0.0
Total program	11.1	10.6	11.0	11.0	11.0	11.0	11.0
Total direct personnel (FTE)	45.1	43.3	48.5	48.3	48.3	48.3	48.3
Total Office of Nuclear Energy, Science and Technology							
Operating expense	16.9	17.7	19.8	20.7	24.2	26.2	26.1
Capital equipment	0.0	(0.3)	0.0	0.1	0.1	0.1	0.1
Total program	16.9	17.4	19.8	20.8	24.3	26.3	26.2
Total direct personnel (FTE)	64.2	72.5	85.7	88.0	88.0	88.0	88.0
Office of Fossil Energy							
Coal—AA							
Total operating	4.6	5.2	4.6	4.9	5.1	5.4	5.4
Total direct personnel (FTE)	15.6	14.6	15.0	15.6	15.6	15.6	15.6
Gas—AB							
Total operating	2.9	3.2	2.8	2.9	2.9	2.9	2.9
Total direct personnel (FTE)	1.9	3.5	1.8	1.2	1.2	1.2	1.2
Petroleum—AC							
Total operating	2.5	2.6	2.8	3.0	3.1	3.3	3.3
Total direct personnel (FTE)	7.5	10.7	10.2	9.5	9.5	9.5	9.5
Fossil Energy Environmental Restoration—AW							
Total operating	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Innovative Clean Coal Technology—AZ							
Total operating	0.0	0.3	0.2	0.2	0.2	0.2	0.2
Total direct personnel (FTE)	0.3	1.8	1.6	0.0	0.0	0.0	0.0

Table S.1
Resources by program by fiscal year (continued)
($ in millions)

	1999	2000	2001	2002	2003	2004	2005
Strategic Petroleum Reserve—SA							
Total operating	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total direct personnel (FTE)	0.3	0.3	1.0	1.0	1.0	1.0	1.0
Total Office of Fossil Energy							
Total operating	10.3	11.4	10.5	11.1	11.4	11.9	11.9
Total direct personnel (FTE)	26.2	30.9	29.6	27.3	27.3	27.3	27.3
Energy Information Administration							
National Energy Information System—TA							
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Total Energy Information Administration							
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Office of Environmental Management							
Environmental Management—EM (ORNL Financial Plan)[c]							
Total operating	28.9	25.1	21.1	21.2	21.6	22.0	22.5
Capital equipment	1.9	(0.2)	0.2	0.2	0.2	0.2	0.2
Total program	30.8	24.9	21.3	21.4	21.8	22.2	22.7
Total direct personnel (FTE)	109.7	111.2	99.5	98.0	98.0	98.0	98.0
Total Office of Environmental Management							
Total operating	28.9	25.1	21.1	21.2	21.6	22.0	22.5
Capital equipment	1.9	(0.2)	0.2	0.2	0.2	0.2	0.2
Total program	30.8	24.9	21.3	21.4	21.8	22.2	22.7
Total direct personnel (FTE)	109.7	111.2	99.5	98.0	98.0	98.0	98.0
Office of Civilian Radioactive Waste Management							
Nuclear Waste Fund—DF							
Total operating	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.1	0.5	0.4	0.4	0.4	0.4	0.4
Total Office of Civilian Radioactive Waste Management							
Total operating	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.1	0.5	0.4	0.4	0.4	0.4	0.4
Undersecretary for National Nuclear Security							
Office of the Deputy Administrator for Defense Programs							
Weapons Activities—DP							
Total operating	20.1	18.6	20.8	21.3	21.6	21.9	22.2
Capital equipment	0.0	(0.1)	1.9	0.4	0.4	0.4	0.4
Construction	(2.0)	0.0	0.0	0.0	0.0	0.0	0.0
Total program	18.1	18.5	22.7	21.7	22.0	22.3	22.6
Total direct personnel (FTE)	78.1	87.8	92.0	90.1	90.1	90.1	90.1
Total Office of Defense Programs							
Total operating	20.1	18.6	20.8	21.3	21.6	21.9	22.2
Capital equipment	0.0	(0.1)	1.9	0.4	0.4	0.4	0.4
Construction	(2.0)	0.0	0.0	0.0	0.0	0.0	0.0
Total program	18.1	18.5	22.7	21.7	22.0	22.3	22.6
Total direct personnel (FTE)	78.1	87.8	92.0	90.1	90.1	90.1	90.1

Table S.1
Resources by program by fiscal year (continued)
($ in millions)

	1999	2000	2001	2002	2003	2004	2005
Deputy Administrator for Defense Nuclear Nonproliferation							
Fissile Materials Disposition—GA							
Total operating	19.6	10.6	35.9	30.3	31.4	30.3	30.1
Total direct personnel (FTE)	50.1	45.7	45.9	43.9	43.9	43.9	43.9
Nuclear Safeguards and Security—GD							
Total operating	0.3	0.1	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.3	0.3	0.0	0.0	0.0	0.0	0.0
Arms Control and Nonproliferation—GJ							
Total operating	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Emergency Management—ND							
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total Deputy Administrator for Defense Nuclear Nonproliferation							
Total operating	20.2	10.7	35.9	30.3	31.4	30.3	30.1
Total direct personnel (FTE)	50.6	46.1	45.9	43.9	43.9	43.9	43.9
Departmental Staff and Support Offices							
Office of Environment, Safety and Health							
Environment, Safety, and Health (Non-Defense)—HC							
Total operating	3.0	1.8	1.8	1.3	1.3	1.3	1.3
Total direct personnel (FTE)	8.2	11.0	10.5	10.2	10.2	10.2	10.2
Environment, Safety, and Health (Defense)—HD							
Total operating	0.2	0.4	0.5	0.4	0.4	0.4	0.4
Total direct personnel (FTE)	0.7	1.8	1.5	0.6	0.6	0.6	0.6
Total Office of Environment, Safety and Health							
Total operating	3.2	2.2	2.3	1.7	1.7	1.7	1.7
Total direct personnel (FTE)	8.9	12.8	12.0	10.8	10.8	10.8	10.8
Office of Counterintelligence							
Counterintelligence—CN							
Total operating	1.4	1.8	1.3	1.4	1.4	1.4	1.4
Total direct personnel (FTE)	6.0	9.2	11.0	11.0	11.0	11.0	11.0
Total Office of Counterintelligence							
Total operating	1.4	1.8	1.3	1.4	1.4	1.4	1.4
Total direct personnel (FTE)	6.0	9.2	11.0	11.0	11.0	11.0	11.0
Office of Security and Emergency Operations							
Security and Emergency Operations—SO							
Total operating	0.0	0.1	5.9	5.9	6.1	6.3	6.5
Capital equipment	0.0	0.0	1.0	0.1	0.0	0.0	0.0
Total program	0.0	0.1	6.9	6.0	6.1	6.3	6.5
Total direct personnel (FTE)	0.0	0.2	31.5	31.6	31.6	31.6	31.6
Total Office of Security and Emergency Operations							
Total operating	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.0	0.2	0.2	0.2	0.2	0.2	0.2
Office of Policy							
Emergency Planning—NC							
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.3	0.2	0.0	0.0	0.0	0.0	0.0

Table S.1
Resources by program by fiscal year (continued)
($ in millions)

	1999	2000	2001	2002	2003	2004	2005
Policy, Analysis, and Systems Studies—PE							
Total operating	0.3	0.1	0.3	0.3	0.3	0.3	0.3
Total direct personnel (FTE)	1.6	2.8	2.7	2.7	2.7	2.7	2.7
Total Office of Policy							
Total operating	0.3	0.1	0.3	0.3	0.3	0.3	0.3
Total direct personnel (FTE)	1.9	3.0	2.7	2.7	2.7	2.7	2.7
Office of Chief Financial Officer							
Pollution Prevention—86							
Total operating	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oak Ridge Landlord—AH (Museum)							
Total operating	1.3	0.4	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
General Administration Program Direction—WA							
Total operating	0.0	0.0	(0.2)	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Office of Chief Financial Officer							
Total operating	1.5	0.4	(0.2)	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Office of Worker and Community Transition							
Worker and Community Transition Program—GG							
Total operating	0.0	3.4	3.3	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total Office of Worker and Community Transition							
Total operating	0.0	3.4	3.3	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Federal Energy Regulatory Commission							
Federal Energy Regulatory Commission—VR							
Total operating	0.5	0.1	1.2	1.2	1.2	1.2	1.2
Total direct personnel (FTE)	3.1	7.3	3.8	3.6	3.6	3.6	3.6
Total Federal Energy Regulatory Commission							
Total operating	0.5	0.1	1.2	1.2	1.2	1.2	1.2
Total direct personnel (FTE)	3.1	7.3	3.8	3.6	3.6	3.6	3.6
Environmental Management (Bechtel Jacobs Company LLC)							
Total operating	65.4	26.1	14.0	7.7	4.4	4.0	4.0
Total direct personnel (FTE)	333.8	129.8	98.0	98.0	98.0	98.0	98.0
Subtotal DOE Programs							
Total operating	447.7	401.0	432.7	417.0	426.4	444.4	466.9
Capital equipment (excluding SNS)	17.4	16.0	15.4	8.1	8.8	8.0	8.0
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Capital equipment, GPE Landlord	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Construction (excluding SNS)	7.6	3.9	6.1	1.0	0.4	0.4	0.4
Construction, GPP Landlord	4.4	4.5	6.3	5.7	5.7	5.7	5.7
SNS construction	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Proposed construction	0.0	0.0	2.5	28.5	26.4	19.1	21.0
Total	582.4	528.9	724.3	743.8	684.6	604.5	584.1
Total direct personnel (FTE)	1665.9	1761.0	1782.0	1756.6	1756.6	1756.6	1756.6

Table S.1
Resources by program by fiscal year (continued)
($ in millions)

	1999	2000	2001	2002	2003	2004	2005
DOE Contractors and Operations Offices							
Total operating	94.6	53.5	55.0	50.0	45.0	40.0	40.0
Total direct personnel (FTE)	354.8	296.6	236.7	231.1	231.1	231.1	231.1
Cooperative R&D Agreements							
Total operating	4.1	7.0	6.1	6.1	6.1	6.1	6.1
Total direct personnel (FTE)	9.6	16.7	16.1	16.1	16.1	16.1	16.1
Total DOE Programs							
Total operating	546.4	461.5	493.8	473.1	477.5	490.5	513.0
Capital equipment (excluding SNS)	17.4	16.0	15.4	8.1	8.8	8.0	8.0
Capital equipment, GPE Landlord	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Construction (excluding SNS)	7.6	3.9	6.1	1.0	0.4	0.4	0.4
Construction, GPP Landlord	4.4	4.5	6.3	5.7	5.7	5.7	5.7
SNS construction	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Proposed construction	0.0	0.0	2.5	28.5	26.4	19.1	21.0
Total	681.1	589.4	785.4	799.9	735.7	650.6	630.2
Total direct personnel (FTE)	2030.3	2074.3	2034.8	2003.8	2003.8	2003.8	2003.8
Work for Others							
Nuclear Regulatory Commission							
Operating expense	9.7	8.1	7.5	7.0	7.0	7.0	7.0
Total direct personnel (FTE)	49.7	43.0	38.0	35.3	35.3	35.3	35.3
Department of Defense							
Operating expense	26.5	33.5	32.5	29.3	29.3	29.3	29.3
Total direct personnel (FTE)	97.8	92.4	95.1	104.4	104.4	104.4	104.4
National Aeronautics and Space Administration							
Operating expense	4.2	4.8	4.9	5.3	5.4	5.4	5.4
Total direct personnel (FTE)	13.7	23.3	23.6	22.9	22.9	22.9	22.9
Department of Health and Human Services							
Operating expense	2.6	2.1	3.0	3.2	3.3	3.5	3.6
Total direct personnel (FTE)	27.5	10.8	10.2	3.0	3.0	3.0	3.0
Environmental Protection Agency							
Operating expense	4.9	4.2	4.2	4.2	4.2	4.2	4.2
Total direct personnel (FTE)	20.2	20.3	18.4	17.7	17.7	17.7	17.7
National Science Foundation							
Operating expense	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel (FTE)	3.0	1.3	0.0	0.0	0.0	0.0	0.0
Federal Emergency Management Agency							
Operating expense	2.0	0.4	0.5	0.5	0.5	0.5	0.5
Total direct personnel (FTE)	5.5	4.5	3.4	3.3	3.3	3.3	3.3
Department of Transportation							
Operating expense	8.9	7.1	6.8	7.0	7.0	7.3	7.6
Total direct personnel (FTE)	26.5	27.6	16.4	17.0	17.0	17.0	17.0
Other Federal agencies							
Operating expenses	0.1	4.9	5.3	8.5	8.3	7.8	7.4
Total direct personnel (FTE)	4.1	6.5	24.5	25.2	25.2	25.2	25.2

Table S.1
Resources by program by fiscal year (continued)
($ in millions)

	1999	2000	2001	2002	2003	2004	2005
Electric Power Research Institute							
Operating expense	0.8	1.0	0.1	0.1	0.1	0.1	0.1
Total direct personnel (FTE)	7.0	3.0	0.7	0.2	0.2	0.2	0.2
Other nonfederal agencies							
Operating expense	15.1	14.0	14.7	14.7	14.7	14.7	14.7
Total direct personnel (FTE)	67.5	69.4	70.5	82.3	82.3	82.3	82.3
Total Work for Others							
Operating expense	75.4	80.1	79.5	79.8	79.8	79.8	79.8
Total direct personnel (FTE)	322.5	302.1	300.7	311.3	311.3	311.3	311.3
Total Program Resources							
Operating expense	621.8	541.6	573.3	552.9	557.3	570.3	592.8
Capital equipment (excluding SNS)	17.4	16.0	15.4	8.1	8.8	8.0	8.0
Capital equipment, SNS	0.6	0.2	0.1	0.1	0.0	0.0	0.0
Capital equipment, GPE Landlord	3.3	3.3	1.7	1.7	2.3	2.3	2.3
Construction (excluding SNS)	7.6	3.9	6.1	1.0	0.4	0.4	0.4
Construction, GPP Landlord	4.4	4.5	6.3	5.7	5.7	5.7	5.7
SNS construction	101.4	100.0	259.5	281.7	214.6	124.6	79.8
Proposed construction	0.0	0.0	2.5	28.5	26.4	19.1	21.0
Total	756.5	669.5	864.9	879.7	815.5	730.4	710.0
Total direct personnel (FTE)	2352.8	2376.4	2335.5	2315.1	2315.1	2315.1	2315.1

[a]GPE = General Plant Equipment.
[b]GPP = General Plant Project.
[c]Prior to March 31, 1998, EM budgets were in the Lockheed Martin Energy Systems, Inc., Central Financial Plan.

Table S.2
Equal Employment Opportunity statistics for 1999

	Total (%)[a]		Minority total (%)		White (%)		Black (%)		Hispanic (%)		Native American (%)		Asian/Pacific Islander (%)	
Job categor	M[b]	F[c]	M	F	M	F	M	F	M	F	M	F	M	F
Officials and managers[d]	377 (87.5)	54 (12.5)	25 (6)	3 (1)	352 (82)	51 (12)	22 (5)	3 (1)	0 (0.0)	0 (0)	0 (0)	0 (0)	3 (0.7)	0 (0)
Professionals[e]	1614 (78.0)	455 (22.0)	154 (7.4)	61 (2.9)	1460 (70.6)	394 (19.0)	42 (2.0)	28 (1.4)	25 (1.2)	3 (0.1)	2 (0.1)	1 (<0.1)	85 (4.1)	29 (1.4)
Technicians	253 (66.1)	130 (33.9)	18 (4.7)	9 (2.3)	235 (61.4)	121 (31.6)	12 (3.1)	8 (2.1)	5 (1.3)	0 (0)	0 (0.0)	0 (0.0)	1 (0.3	1 0.3)
Office and clerical	10 (1.7)	563 (98.3)	3 (0.5)	64 (11.2)	7 (1.2)	499 (87.1)	3 (0.5)	54 (9.4)	0 (0.0)	5 (0.9)	0 (0.0)	1 (0.2)	0 (0.0)	4 (0.7)
Craft workers (skilled)	445 (97.2)	13 (2.8)	29 (6.3)	0 (0.0)	416 (90.8)	13 (2.8)	27 (5.9)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.4)	0 (0.0)
Operatives (semi-skilled)	101 (80.2)	25 (19.8)	18 (14.3)	5 (4.0)	83 (65.9)	20 (15.9)	17 (13.5)	5 (4.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.8)	0 (0.0)
Laborers (unskilled)	44 (67.7)	21 (32.3)	13 (20.0)	9 (13.8)	31 (47.7)	12 (18.5)	13 (20.0)	9 (13.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Service workers	61 (67.8)	29 (32.2)	9 (10.0)	12 (13.3)	52 (57.8)	17 (18.9)	9 (10.0)	9 (10.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (1.1)	0 (0.0)	2 (2.2)
Total	2905 (69.2)	1290 (30.8)	269 (6.4)	163 (3.9)	2636 (62.8)	1127 (26.9)	145 (3.5)	116 (2.8)	30 (0.7)	8 (0.2)	2 (<0.1)	3 (0.1)	92 (2.2)	36 (0.9)

[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.

Table S.3
ORNL staff composition (as of December 31, 1999)[a]

	Ph.D.	M.S.	B.S./B.A.	Other	Total
Professional staff					
Scientists	472	170	116	23	781
Engineers	247	230	163	88	728
Management/administrative	110	260	322	270	962
Support staff					
Technicians	0	4	82	280	366
All other	0	5	96	1185	1286
Total ORNL staff	829	669	779	1846	4123

[a]Includes both full-time and part-time employees.

Table S.4
Estimated subcontracting and procurement by fiscal year
($ in millions—obligated)

	1999[a,b]	2000[c]	2001	2002
Universities	19.9	28.0	28.0	28.0
All others	155.5	154.0	154.0	154.0
Transfers to other DOE facilities	3.2	3.0	3.0	3.0
Total external subcontracts and procurements	178.6	185.0	185.0	185.0

[a]Actual.
[b]Includes procurements for the Spallation Neutron Source (SNS).
[c]Does not include procurements for SNS.

Table S.5
Estimated small and disadvantaged business procurement by fiscal year

	1999[a]	2000[b]
Total small and disadvantaged business procurement, in millions of dollars	76.9	74.0
Small and disadvantaged business procurement as a percentage of total procurement	43%	40%

[a]Includes procurements for the Spallation Neutron Source (SNS).
[b]Does not include procurements for SNS.

Table S.6

Experimenters at ORNL's designated user facilities in FY 1999[a]

	Number of experimenters	Non-ORNL organizations
Bioprocessing Research and Development Center		
ORNL	4	—
Other U.S. government laboratories	0	0
U.S. universities	2	1
U.S. industry	5	2
International organizations	0	0
Total	**11**	**3**
Buildings Technology Center		
ORNL	60	—
Other U.S. government laboratories	10	3
U.S. universities	4	4
U.S. industry	46	40
International organizations	3	2
Total	**123**	**49**
Californium User Facility for Neutron Sciences		
ORNL	0	—
Other U.S. government laboratories	2	2
U.S. universities	1	1
U.S. industry	0	0
International organizations	0	0
Total	**3**	**3**
High Flux Isotope Reactor[b]		
ORNL	60	—
Other U.S. government laboratories	15	5
U.S. universities	49	28
U.S. industry	7	5
International organizations	20	14
Total	**151**	**52**
High Temperature Materials Laboratory		
ORNL	3	—
Other U.S. government laboratories	2	2
U.S. universities	59	27
U.S. industry	73	26
International organizations	0	0
Total	**137**	**55**
Holifield Radioactive Ion Beam Facility		
ORNL	28	—
Other U.S. government laboratories	0	0
U.S. universities	36	14
U.S. industry	0	0
International organizations	23	4
Total	**87**	**18**
Metals Processing Laboratory User Facility (MPLUS)		
ORNL	17	—
Other U.S. government laboratories	0	0
U.S. universities	5	3
U.S. industry	25	14
International organizations	0	0
Total	**47**	**17**

Table S.6 (continued)

Experimenters at ORNL's designated user facilities in FY 1999

	Number of experimenters	Non-ORNL organizations
Metrology R&D Laboratory[c]		
ORNL	2720	—
Other U.S. government laboratories	0	0
U.S. universities	0	0
U.S. industry	271	2
International organizations	0	0
Total	**2991**	**2**
Oak Ridge Electron Linear Accelerator		
ORNL	10	—
Other U.S. government laboratories	1	1
U.S. universities	6	3
U.S. industry	0	0
International organizations	3	3
Total	**20**	**7**
Oak Ridge National Environmental Research Park[d]		
ORNL	21	—
Other U.S. government laboratories	16	4
U.S. universities	51	23
U.S. industry	0	0
International organizations	2	2
State and educational agencies	26	4
Total	**116**	**33**
Shared Research Equipment (SHaRE) Facility		
ORNL	62	—
Other U.S. government laboratories	4	3
U.S. universities	31	22
U.S. industry	2	2
International organizations	9	9
Total	**108**	**36**
Surface Modification and Characterization Research Facility		
ORNL	32	—
Other U.S. government laboratories	2	2
U.S. universities	47	15
U.S. industry	11	7
International organizations	2	2
Total	**94**	**26**

[a]Three designated user facilities are not included: the Mouse Genetics Research Facility and the Physical Properties Research Center, which were not fully operational in FY 1999, and the Computational Center for Industrial Innovation, which was inactive in FY 1999. The Atomic Physics EN Tandem Accelerator has been removed from the list of active user facilities.

[b]Statistics include only researchers who conduct experiments at the facility (not those "users" who request services, such as materials irradiation and isotope production, that are performed by ORNL staff).

[c]99% of this effort is devoted to the calibration traceability programs carried out for DOE's Oak Ridge Complex (ORNL, the Y-12 National Security Complex, and the East Tennessee Technology Park).

[d]Totals do not include 11,975 individuals who participated in the Ecological and Physical Sciences Study Center and the High School Honors Program.

Table S.7
University and science education statistics

	FY 1999		
	Total	Minor-ities	Women
Precollege student programs			
Adventures in Supercomputing	360	101	146
Appalachian Regional Commission Honors Academy	44	7	19
Project SEED/Hispanic SEED	6	1	5
Special Honors Study	2	1	0
SciCops Camp	26	2	7
Science Explorers Camp	37	4	16
Ecological and Physical Sciences Study Center	11,973	*a*	*a*
Women in Science and Technology	35	*a*	35
Precollege teacher programs			
Adventures in Supercomputing	5	1	3
Appalachian Regional Commission Teacher Leadership Institute	14	2	8
Internet Tutorial Project	11	2	4
NTEP Elementary Science Leadership Institute	3	0	2
Teacher Research Participation	4	0	3
Women in Science and Technology	7	*a*	7
Undergraduate programs			
Energy Research Undergraduate Laboratory Fellowships	112	45	40
Great Lakes Colleges Association/Associated Colleges of the Midwest Science Semester	16	2	9
Professional Internship Program	26	3	9
Community College Initiative	17	10	7
Technology Internship Program	4	0	1
Graduate programs			
Graduate Student Research Participation Program	1	0	1
Professional Internship Programs	33	12	15
Postgraduate programs			
DOE Postdoctoral Programs	114	4	24
Postgraduate Research Training Program	24	2	8
Faculty programs			
Faculty Research Participation	13	7	0
Great Lakes Colleges Association/Associated Colleges of the Midwest	4	0	1
HBCU Faculty Research	3	2	1

[a]Not tracked.

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