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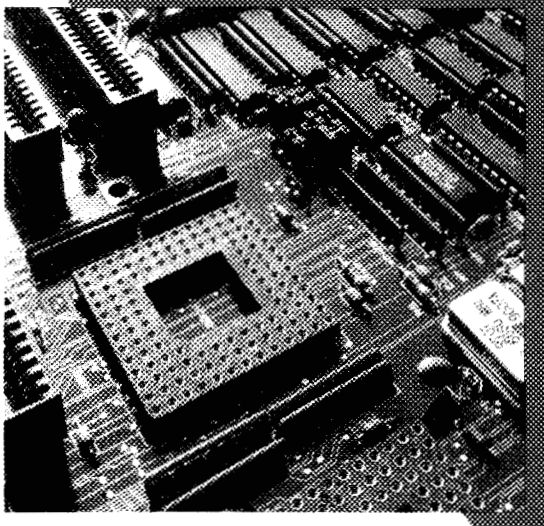

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Institutional Plan
FY 1994–FY 1999

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Oak Ridge National Laboratory Institutional Plan FY 1994–FY 1999

September 1993

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Contents

1. Laboratory Director's Statement 1-1

2. Laboratory Missions 2-1

3. Laboratory Strategic Plan 3-1

Situation Analysis 3-1
Assumptions 3-1
Strengths, Weaknesses, Opportunities, and Threats 3-2
People 3-2
Physical Resources 3-2
Operations 3-2
Environmental, Safety, and Health Practices 3-2
External Relations 3-3
Research Programs 3-3

Visions and Strategic Objectives 3-3
Vision 3-3
Overall Research and Development Directions 3-4
Energy Technologies 3-4
Environmental Technologies 3-5
Engineering and Manufacturing Sciences and Technologies 3-5
Physical and Materials Sciences 3-6
Computational Sciences 3-6
Environmental, Life, and Social Sciences 3-7
Education 3-8
Strategic Objectives 3-8
Programmatic Goals 3-8
Institutional Goals 3-10

Strategic Issues 3-11

Strategies 3-11

4. Summary of Major Initiatives 4-1

Advanced Neutron Source 4-1

High-Performance Computing R&D 4-3
Grand Challenges 4-4
Groundwater Transport and Remediation 4-4

Materials Simulation 4-4
Global Change 4-5
Advanced Technology 4-5
The Intel Paragon Computers and the CCS Staff 4-5
Evaluation of Developing Systems 4-6
Networking 4-7
Adventures in Supercomputing 4-7
Industrial Participation 4-8

Center for Biological Sciences 4-8

Advanced Materials, Design Methods, and Manufacturing Technology 4-12

Biotechnology 4-14
Structural Biology 4-15
Cellular Studies 4-16
Analysis Techniques 4-17
Bioprocessing 4-18
Environmental Biotechnology 4-19
Social Issues 4-20
Budget 4-20

Environmental, Life, and Social Sciences Complex 4-20
Earth Systems Facility 4-21
Biological Imaging and Advanced Photonics Laboratory 4-23
General Plant Projects 4-23
Other Construction 4-23

Materials Science and Engineering Complex 4-24
Center for Study of Advanced Materials 4-25
Solid State Research and Processing Science Center 4-26
Center for Advanced Microstructural Analysis 4-26
Composite Materials Laboratory 4-27
Office of Guest and User Interactions 4-28

Oak Ridge as a National Fusion Nuclear Site 4-28

Transportation Technologies and Systems 4-29

Center for Environmental Technology 4-32

Energy and Environmental R&D for a Sustainable Future 4-33

Other Initiatives 4-35

5. Scientific and Technical Programs 5-1

U.S. Department of Energy 5-1
Office of Energy Research 5-1
Magnetic Fusion—AT 5-2
Theory 5-2
Atomic Physics 5-3
Spherical Tokamak Program 5-3
Advanced Toroidal Facility 5-4
Edge Physics, Particle Control, and Plasma Technology 5-4

Materials Program 5-6
Advanced Systems Program 5-7
Technical and Scientific Applications 5-9
High-Energy Physics—KA 5-9
Continuing Initiative: High-Energy Physics Research Program and the Oak Ridge Detector Center 5-9
Nuclear Physics—KB 5-11
Heavy-Ion Physics Task—KB02 5-11
Continuing Initiative: Radioactive Beams/Recoil Mass Spectrometer 5-12
Nuclear Theory Program—KB03 5-14
Low-Energy Nuclear Physics Program—KB04 5-14
Basic Energy Sciences—KC 5-14
Materials Sciences—KC02 5-14
Chemical Sciences—KC03 5-17
Continuing Initiative: Development of Melton Valley as a Strategic Resource for Nuclear and Radiochemical Technology 5-21
Continuing Initiative: Center for Excellence in Research Reactors 5-22
Continuing Initiative: Retention of the Pool Critical Assembly 5-24
Engineering and Geosciences—KC04 5-25
Advanced Energy Projects—KC05 5-26
Applied Mathematical Sciences—KC07 5-26
Energy Research Analyses—KD 5-27
Multiprogram Energy Laboratories Facilities Support—KG 5-27
Biological and Environmental Research—KP 5-27
New Initiative: Computational Biosciences 5-28
Analytical Technology—Dosimetry Research and Measurement Science—KP01 5-30
Continuing Initiative: Advanced Photonics for Environmental Needs 5-31
Continuing Initiative: Biological Imaging and Analysis Center 5-32
Environmental Research—KP02 5-32
Continuing Initiative: Subsurface Science Research 5-35
Health Effects and General Life Science—KP03, KP04 5-36
Continuing Initiative: ORNL Genome Program 5-39
Carbon Dioxide Research—KP05 5-41
Continuing Initiative: Center for Global Environmental Studies 5-42
Medical Applications—KP06 5-46
Superconducting Super Collider—KS 5-47
University and Science Education—KT and University and Science Education—Defense-Related—KV 5-47
Continuing Initiative: Education Technology 5-47
Laboratory Technology Transfer—KU 5-49
Office of Nuclear Energy 5-49
Nuclear Energy R&D—AF 5-50

Commercial Reactor Programs 5-50
Space Nuclear Power 5-50
Continuing Initiative: Center for Excellence in Research Reactors 5-50
Continuing Initiative: Retention of the Pool Critical Assembly 5-50
Continuing Initiative: Actinide Recycle 5-51
Naval Reactors—AJ 5-51
Radiation Shielding Information Center 5-51
Isotope Production and Distribution Program—ST 5-51
Assistant Secretary for Defense Programs 5-52
Weapons Activities—GB 5-52
Radiation Shielding Information Center 5-52
Technology Transfer Initiative 5-53
Nuclear Safeguards and Security—GD 5-54
Detection of High Explosives by Tandem Mass Spectrometry—GD06 01 5-54
Materials Production—GE 5-54
Assistant Secretary for Energy Efficiency and Renewable Energy 5-54
Electric Energy Systems—AK 5-55
Energy Storage Systems—AL 5-55
Geothermal Systems—AM 5-56
Hydropower—CE 5-56
Solar Energy—EB 5-56
Buildings Sector—EC 5-57
Industrial Energy Conservation—ED 5-59
Transportation—EE 5-60
Technical and Financial Assistance—EF 5-62
Utility Sector—EK 5-62
Assistant Secretary for Fossil Energy 5-62
Coal—AA 5-63
Petroleum—AC 5-65
Energy Technology Center Program Direction—AN 5-65
Fossil Energy Environmental Restoration—AW 5-65
Innovative Clean Coal Technology—AZ 5-65
Strategic Petroleum Reserve—SA 5-65
Assistant Secretary for Environment, Safety, and Health 5-66
Environmental Safety and Health—HA01 5-66
Environmental Guidance and Compliance 5-66
NEPA Oversight 5-67
Environmental Audit 5-67
Safety Policy and Standards 5-67
Neutron Dosimetry 5-67
Nuclear Accident Dosimetry Performance Test Program 5-67
Continuing Initiative: Center for Risk Management 5-68
Continuing Initiative: Health Physics Instrumentation Center of Excellence 5-70
Epidemiological Activities—HR 5-71
Office of Security Evaluations—HS 5-72

Policy and Management Support for the Office of Nuclear Energy—KK05 5-72
DOE Standards Program 5-72
DOE Performance Indicators Program 5-72
Office of Nuclear Safety—NS 5-72
Office of Civilian Radioactive Waste Management 5-73
Nuclear Waste Fund—DB 5-73
Assistant Secretary for Environmental Restoration and Waste Management 5-74
Environmental Restoration 5-74
Waste Management 5-76
Technology Development 5-76
Quality Assurance and Quality Control 5-77
West Valley Demonstration Project Vitrification Facility—EX70 5-78
Energy Information Administration 5-78
Other DOE Programs and Installations 5-79
Office of the Associate Deputy Secretary for Field Management 5-79
In-House Energy Management—WB 5-79
Strategic Facilities Utilization Program 5-79
Assistant Secretary for Policy, Planning and Program Evaluation 5-80
Policy, Planning, and Analysis—PE 5-80
Federal Energy Regulatory Commission 5-80
Other DOE Organizations 5-81
Other Energy Systems Sites 5-81
Other ORNL Programs 5-82
Reactor Operations 5-82
Robotics and Intelligent Systems Program 5-83

Work for Others 5-84
Federal Organizations 5-86
Nuclear Regulatory Commission 5-86
Nuclear Regulatory Research 5-86
Analysis and Evaluation of Operational Data 5-88
Nuclear Reactor Regulation 5-88
Nuclear Material Safety and Safeguards 5-88
Other Offices 5-89
U.S. Department of Defense 5-89
Army 5-89
Navy and Marine Corps 5-91
Air Force 5-92
Military Transportation 5-93
Defense Nuclear Agency 5-93
Ballistic Missiles Defense Organization 5-94
Other U.S. Department of Defense Agencies 5-94
National Aeronautics and Space Administration 5-94
U.S. Department of Health and Human Services 5-95
U.S. Environmental Protection Agency 5-96
National Science Foundation 5-98

Federal Emergency Management Agency 5-99
U.S. Agency for International Development 5-99
U.S. Department of Transportation 5-100
U.S. Department of Commerce 5-101
Other Federal Agencies 5-102
Nonfederal Organizations 5-102
Electric Power Research Institute 5-102
American Petroleum Institute 5-103
Joint Institute for Energy and Environment 5-103
Other Nonfederal Organizations 5-104

Laboratory Directed R&D Program 5-104

6. Environment, Safety, and Health 6-1

ES&H Goals and Objectives 6-1

Current Conditions 6-4
ES&H Expectations and Regulatory Requirements 6-4
ORNL Variances from Current Expectations 6-5
Limited Resources 6-5
Management Systems 6-5
Leadership in ES&H Matters 6-6

ES&H Policies, Organization, and Management 6-6

ES&H Plans and Initiatives 6-7

Environmental Restoration and Waste Management Activities 6-9
Environmental Restoration 6-10
Waste Management 6-13

Landlord-Funded ES&H 6-14

7. Technology Transfer and Science and Mathematics Education 7-1

Technology Transfer Plan 7-1
Overview 7-1
Vision 7-2
Strategic Objectives 7-2
Resources and Staffing 7-2
Industry-Laboratory Cooperative Projects 7-2
User Facilities 7-4
Guest Research 7-4
Cooperative Research 7-8
Long-Range Plans 7-8
Patents and Licensing 7-9
Technology Transfer Achievements 7-9
Blood Chemistry Analyzer 7-9
Large Single Crystals of Magnesium Oxide 7-11
The ANDROS Mark VI Robot 7-11
Thin-Film Lithium Battery 7-11

Science/Math Education Support Programs 7-12
University Consortia 7-13
R&D Subcontracts 7-14
Research Collaborations 7-14
Facilities and Equipment at ORNL 7-15
Precollege Programs 7-15
Undergraduate Programs 7-16
Graduate and Postgraduate Programs 7-17
Faculty Programs 7-18
Minority Educational Institutions 7-18
The University of Tennessee at Knoxville 7-19
Science Alliance 7-19
UTK Graduate Schools at ORNL 7-19
Summary 7-20

8. Human Resources 8-1

Laboratory Personnel 8-1
Recognition Programs 8-2
Training and Education 8-3

Affirmative Action and Equal Employment Opportunity 8-3
EEO/AA Structure and Function 8-4
Promoting Cultural Diversity 8-4
Developmental Activities 8-4
Goals and Strategies 8-7

9. Site and Facilities 9-1

Laboratory Description 9-1

Facilities Plans and Options 9-5

General-Purpose Facilities Plans 9-7
General Plant Projects 9-7
General-Purpose Equipment 9-10

Inactive/Surplus Facilities Plan 9-12

Facilities Resource Requirements 9-12

10. Information Resource Management 10-1

Goals and Objectives 10-1

Current Situation 10-2
Scientific Computing 10-2
Administrative Computing 10-3
Networking 10-3
Scientific and Technical Information 10-3
Center for Environmental Engineering 10-4
Carbon Dioxide Information Analysis Center 10-4
Toxicology Information Response Center 10-5
ORNL Environmental Restoration Data Management System 10-5

Oak Ridge Environmental Information System 10-5
Remedial Action Program Information Center 10-5
Environmental Mutagen Information Center 10-5
Chemical Unit Record Estimates Data Base 10-6
Human Genome Management Information System 10-6
Information Management Activities 10-7
Business Information 10-7
Technology Transfer 10-7

Strategies 10-7
Scientific Computing 10-7
Administrative Computing 10-8
Networking 10-8
Information Management 10-9

Resources and Initiatives 10-9

11. Resource Projections 11-1

Appendix A-1

Organization Chart A-3

Abbreviations A-5

Acknowledgments A-13

Photographs and Drawings A-14

1 • Laboratory Director's Statement

Along with other research facilities established during World War II, Oak Ridge National Laboratory (ORNL) sprang from one urgent objective: creation of an atomic bomb. The scope of this endeavor required a new model, a new approach to science.

In the United States and Europe, the solution was large government research centers where scientists, engineers, mathematicians, and others could collaborate on their nations' highest defense priority. Over the past five decades, these research centers have expanded on their success by moving beyond their original mandate to address the great scientific challenges of our time.

ORNL's 50th anniversary coincides with a watershed—a time of transition from one great era to another. At this turning point, it seems appropriate to look at the fields of science that evolved from our World War II origins and to examine the challenges that lie ahead.

First, and most obvious, is nuclear power. In the two decades following the war, there was tremendous activity and excitement in the field of nuclear power, as many different reactor designs were developed and piloted at ORNL and other laboratories. ORNL has extended its nuclear foundations to build a broader energy research and development (R&D) enterprise, one that now develops diverse end-use and production technologies ranging from fuel-efficient hybrid vehicles to biomass energy production.

A second example is materials science. In the 1940s, we began exploring the causes and effects of radiation damage in reactor materials—and designing new alloys that could withstand neutron bombardment and resist embrittlement. Work on reactor designs over the years also led to heat-resistant ceramic fuel elements. These, in turn, have led to toughened structural ceramics for such applications as advanced diesel engines and gas turbines.

Nuclear science also spawned such revolutionary materials developments as ion-beam processing for complex semiconductors and ion implantation for hard, corrosion-resistant surfaces. On the horizon is a vast array of new products and processes made possible through advanced materials. Among them are new semiconductor technologies, optical ceramics for communication networks and optical computers, fusion materials, and polymers with tremendous surface hardness and new electromagnetic properties.

Partly because of our strong tradition in materials science, ORNL's top scientific priority for the future is the Advanced Neutron Source. The world's most powerful research reactor, ANS will be a peerless facility for probing the structure of matter in the fields of material science, biology, polymer science, chemistry, and solid-state physics.

Our wartime work in biology focused on the effects of radiation on people and animals, leading to standards for radiation exposure that are still observed worldwide. The program that evolved from these beginnings has produced diverse and far-reaching results: discovery of the role of the Y chromosome in determining gender in mammals, discovery of the function of messenger RNA, the first successful bone marrow transplant, and the development of techniques for freezing animal and human embryos for later implantation.

Today, our biology research has two strong focuses: first, understanding the mechanisms of genetic damage, using research tools such as transgenic mice to help us understand human

development; second, exploring and reengineering the fundamental workings of the cellular proteins that regulate the intricate biochemistry of life. Work in both these areas will be greatly strengthened by the Center for Biological Sciences, another top ORNL initiative. Promising applications of R&D to be conducted there include biotechnology for energy production and waste treatment, protein engineering for boosting crop yields, development of monoclonal antibodies for cancer treatment, and the mapping of human genes so that we can understand—and begin to cure—genetic diseases and disorders.

One inescapable result of our wartime work is a legacy of environmental problems. Over the years we have developed a number of innovative ways of addressing these problems, including techniques for isolating radioactive waste, standards for waste shipment, and genetically engineered organisms that consume waste or that emit light to show when, where, and how quickly waste is being consumed.

We have expanded our focus to include broader environmental issues, such as nutrient cycling through various ecosystems, the acid-rain cycle, and the effects of different types of power plants. In the future, we expect to address two major challenges: improving ways to dispose of nuclear and hazardous wastes, and increasing our understanding of such complex environmental phenomena as ozone depletion and global climate change. Much of this work will take place in ORNL's Center for Global Environmental Studies and the new Center for Environmental Technologies at the Oak Ridge K-25 Site.

Finally, high-performance computing is a clear case of a weapons spin-off, developed and first employed specifically for the modeling of bombs. Since then, it has been applied to a wide range of mathematically complex challenges, including designing aerodynamic spacecraft and modeling the microstructure of superconductors.

Building on the foundation established by our new Center for Computational Sciences, ORNL is becoming one of the nation's premier centers for applied computational sciences. For example, ORNL is one of the Department of Energy's two research centers for high-performance computing, and our new Intel Paragon is one of the world's most powerful supercomputers. Among the high-priority areas to be addressed with computational tools are mapping the human genome, modeling global climate change, and engineering advanced materials.

Clearly, our missions have evolved remarkably over the past 50 years, and they will continue to do so over the next 50. In one respect in particular, I expect to see considerable change: collaboration across public and private lines will increase to meet the needs of the nation's citizens, and the national laboratories will play an increasingly active role in revitalizing the U.S. economy.

This is already happening to a remarkable degree. As recently as the late 1970s, for example, we hosted only a few hundred visiting researchers a year in Oak Ridge. Last year, by contrast, we hosted 4,300 guest researchers and 24,000 students at ORNL. With other national laboratories, ORNL is entering into cooperative R&D agreements with industry, licensing government-developed technologies, and rewarding scientists when inventions are successfully commercialized.

Over the past several years, we have seen astonishing demonstrations of how political boundaries and barriers can blur and sometimes vanish. So, too, can scientific ones. Now more than ever, the challenges to humanity require interlaboratory, international collaboration: new energy sources for the future; an understanding of genetic diseases and disorders; better ways of handling the toxic, hazardous, and radioactive downside of our progress.

The national laboratories must be the centers of intellect to solve these problems. The stakes are very high—perhaps far higher than they were 50 years ago. The world's population is likely to double by the middle of the next century. Ways must be found to help developing nations improve their lot while preserving the natural environment. Otherwise, everyone will pay the price: widespread deforestation, rising levels of greenhouse gases, climate change, worsening famines, and growing tension between the haves and the have-nots.

All of us share in the opportunities and responsibilities facing us. During the past half-century, ORNL accomplished a great deal. During the next, there is much, much more for us to do.

2 • Laboratory Missions

The Oak Ridge National Laboratory (ORNL) is a Department of Energy multiprogram laboratory. It is managed for the Department by Martin Marietta Energy Systems, Inc. The mission of the Laboratory is to conduct basic and applied research and development (R&D) to advance the nation's energy security, environmental quality, scientific knowledge, educational foundations, and technological competitiveness. The Laboratory is committed to excellence in all of its activities and will be operated in compliance with environmental, safety, and health laws and regulations. The Laboratory also performs work in collaboration with other federal agencies, industry, and universities.

ORNL's mission comprises activities in the following areas, which are representative of the Laboratory's core competencies:

- **Energy production and end-use technologies.** The Laboratory conducts applied R&D in energy efficiency, renewable energy, magnetic confinement fusion, nuclear fission, biomass, and fossil fuels.
- **Environmental sciences and technologies.** Research areas include global change, earth sciences, environmental biology, analysis and assessment, risk management, and environmental technology development. ORNL develops techniques to characterize, monitor, and correct existing problems; to prevent future problems; and to reduce waste generation.
- **Engineering and manufacturing sciences and technologies.** Work covers traditional areas that include chemical processing, solid and fluid mechanics, thermal sciences, and diffusion phenomena and new areas such as chaos theory, signal processing, and artificial intelligence.
- **Physical, chemical, and materials sciences.** Experimental and theoretical research is undertaken to investigate fundamental problems, to advance scientific knowledge, and to lay the foundation for new technologies of national significance.
- **Computational sciences.** Advanced computational techniques and high-performance computing resources are applied to challenging problems in science and engineering.
- **Biological and life sciences.** A broad program spans fields from molecular biology to ecology and includes mammalian genetics, structural biology, protein engineering, health sciences, and biomedical technology, with applied research in the social and economic sciences.
- **Scientific and technological user facilities.** ORNL designs, builds, and operates unique research facilities for the benefit of researchers from universities, industry, other research institutions, and other federal agencies.
- **Science and technology transfer.** ORNL works with the private sector, universities, and other federal agencies to improve national economic competitiveness by the transfer of technology and scientific knowledge.
- **Education.** ORNL helps to prepare the scientific and technical work force of the future by offering a variety of learning and R&D experiences to students and faculty members from the preschool level through postdoctoral studies and by establishing partnerships with educational institutions from elementary schools to universities.

ORNL's core competencies can be viewed as a set of four technical foundations and eight integrated capabilities. The technical foundations underpin the integrated capabilities, and the integrated capabilities cross-cut the technical foundations. The four technical foundations, each of which represents an area of significant scientific strength and impact and supports several integrated capabilities, are

- physical, chemical, and materials sciences,
- biological, environmental, and social sciences,
- engineering sciences, and
- computational sciences and informatics.

The eight integrated capabilities, each of which represents an area of significant technical strength and impact and integrates several technical foundations, are

- energy production and end-use technologies,
- environmental technologies,
- advanced materials development and processing,
- manufacturing technologies,
- transportation technologies,
- biotechnologies,
- integrated assessments, and
- development and operation of national user facilities.

Presenting these technical foundations and integrated activities as a matrix (Table 2.1) provides a profile of ORNL.

Table 2.1
Matrix of ORNL's core competencies

	TECHNICAL FOUNDATIONS			
INTEGRATED CAPABILITIES	Physical, Chemical, and Materials Sciences	Biological, Environmental, and Social Sciences	Engineering Sciences	Computational Sciences and Informatics
Energy Production and End-Use Technologies	✓	✓	✓	✓
Environmental Technologies	✓	✓	✓	✓
Advanced Materials Development and Processing	✓		✓	✓
Manufacturing Technologies	✓	✓	✓	✓
Transportation Technologies	✓	✓	✓	✓
Biotechnologies	✓	✓	✓	✓
Integrated Assessments	✓	✓	✓	✓
Development and Operation of National Research Facilities	✓	✓	✓	✓

3 • Laboratory Strategic Plan

Situation Analysis

Assumptions

This plan, which covers a 20-year period, is based on a number of assumptions about future events and conditions that will affect Oak Ridge National Laboratory (ORNL) but that we do not control. First, we assume that ORNL will remain a Department of Energy–owned, contractor-operated national laboratory. The Laboratory's most important role will continue to be to support the missions of the Department of Energy. The current broad mission areas of the Department will continue, but the balance of activities will change substantially. Over the planning period, the main themes of the Department and its laboratories will be energy, the environment, international competitiveness, and the fundamental scientific knowledge required to deal with these issues and to keep the United States the world leader in science and technology. The Department will increasingly be called on to lend assistance, through its national laboratories, to other agencies of government. This assistance will be most needed in environmental restoration and waste management, in infrastructure revitalization, in high-performance computing and networking, and in the competitiveness arena. We believe that ORNL has the skills and the dedication to contribute in important ways to the four main themes of the next two decades.

Even though ORNL and the other national laboratories have skills and facilities that are valuable to the nation, there is no guarantee that the laboratories' services will be used. The substantial decline in defense work, coupled with a continuing federal budget problem, will result in considerable pressure on the Department to downsize and consolidate some research and development (R&D) activities. At the same time, a large fraction of the Department's budget must go toward correcting "legacy" problems, further eroding the capability to conduct R&D. What this adds up to, we believe, is that ORNL and the Department's other laboratories will be challenged to deliver exceptional value for the research dollar. Laboratories that do this will be pivotal to the well-being of the nation. Those that are successful will

- be innovators and risk takers, finding ways to accomplish things even in the face of adversity;
- be intellectual leaders in applying science and technology to socially important issues;
- be effective in explaining new ideas and new programs of national significance to the public, opinion makers, political leaders, industry, and potential sponsors;
- be organized in ways that permit flexibility in assembling cross-disciplinary teams to address new problems or opportunities;
- be competitive with other multidisciplinary research institutions in terms of cost;
- be dedicated to satisfying the needs of the sponsor and other customers;
- be "user friendly" to collaborators from universities, industry, and international institutions;
- be effective in bridging the gap between laboratory research and commercial applications; and
- be leaders in collaborative work with other national laboratories and with industry.

Strengths, Weaknesses, Opportunities, and Threats

People

A major strength of the Laboratory is its experienced research staff—a staff with world-class credentials in many fields of science and engineering. In addition to its overall excellence, another important characteristic of the staff of ORNL is a pervasive spirit of cooperation and mutual support. This trait makes it possible for the Laboratory to quickly mobilize multidisciplinary teams to deal with important issues or opportunities.

While the experience of the staff is a major asset, it also presents a challenge. Approximately one-third of the professional staff will retire during the planning period. Replacing these leaders with people of equal ability will require a continuing effort to recruit and develop top-notch staff members. Particular emphasis must be placed on increasing the diversity of the staff.

Physical Resources

The availability of a wide variety of first-class research tools and facilities is a significant strength of ORNL. Not only do these research facilities serve the missions of the Department; they are also used by many from the national and international research communities.

Although major research facilities are a strength, the Laboratory's general infrastructure is inadequate, and some of the smaller scale research equipment is obsolete. Insufficient investments in maintenance and in new general-purpose buildings have resulted in inadequate space to house the staff and the increasing number of guests. The generally shabby appearance of the campus is a detriment to recruiting and to developing collaborations with industry. A major effort to revitalize the Laboratory's infrastructure and to update some of the research equipment is required during the planning period.

Operations

Most of the Laboratory's traditional supporting activities—finance, maintenance, libraries, publications, security, personnel—are fundamentally sound. However, the new orders, rules, and regulations imposed in the late 1980s added a costly new bureaucracy that diverted resources and management attention from research and many of the important supporting functions. To meet the competitive challenges of the future, ORNL must

- eliminate bureaucratic impediments to doing research,
- reduce the cost of doing business, including overhead burden and construction costs, and
- improve teaming between the research staff and the support staff.

Environmental, Safety, and Health Practices

Like many institutions, ORNL did not keep up with the changing times in complying with modern standards for protecting the environment and maintaining a safe and healthful workplace. However, through one of the most intense and focused efforts in the Laboratory's history, we corrected many of the problems and set ORNL on a new course. Much has been accomplished, but much remains to be done. Continuing attention to protecting and restoring the environment and to guarding the safety and health of our people and the public is needed to support the Laboratory's commitment to full compliance with environmental, safety, and health laws and regulations.

External Relations

The Laboratory is a leader in establishing cooperative relationships with industry and universities. These relationships span a broad range of activities, including cooperative R&D agreements (CRADAs) with industry, licensing of ORNL-developed technologies, collaborative research, and provision of user facilities for guest researchers. All of these areas have shown remarkable growth in the last few years; for example, the number of guests has grown from about 1000 in 1984 to more than 4000 in 1992. The Laboratory has a good reputation for delivering what is promised, on schedule and within budget.

The future demands that ORNL continue to improve on its good external relationships. In particular, we need to make it easier for guest researchers and industrial partners to gain access to facilities and services, and we need to make the Laboratory more hospitable—more like a research campus and less like a secret World War II facility.

Research Programs

ORNL is a diversified laboratory with a broad mission carried out by a multidisciplinary staff through several major program areas. We conclude that ORNL should remain a broad-based, multiprogram laboratory to best serve the future needs of the Department and the nation. The next one to two decades hold the promise of being one of the most challenging and exciting periods in our history. It will be a period of revolutionary changes in almost every area of science and technology in which ORNL is involved and a period of great opportunity for those research institutions that are prepared to meet the challenge.

Visions and Strategic Objectives

Vision

> Oak Ridge National Laboratory should strive to be a place that is so well recognized for its excellence that students in certain fields of science and engineering regard working at the Laboratory as an essential element in their education.
>
> Alvin W. Trivelpiece, Director, Oak Ridge National Laboratory

This vision stems from a deeply ingrained set of values about the Laboratory and its purpose. It assumes that the Department of Energy's national laboratories, and this national laboratory in particular, are very special places. As a national laboratory, ORNL has an obligation to serve national needs through science and technology. Advances in science and technology are essential for a better future for the United States and the world. ORNL will be a place of scientific and technical excellence that contributes to the storehouse of basic scientific knowledge and that uses this knowledge to solve important problems and to create new opportunities of social value. The credo by which we want to live is, "We bring science to life." To achieve this vision, it is imperative that we maintain our intellectual honesty and scientific integrity.

Overall Research and Development Directions

Energy Technologies

The Laboratory's broad goal in energy technology R&D is to remain a major contributor to the Department's energy mission by conceiving and developing new technologies that are environmentally sustainable, safe, and economical and that are important to the nation and the world. The program will encompass both energy-efficient end-use and conversion technologies and energy supply technologies.

The existing broad-based program in energy-efficient end-use and conversion technologies will continue, with R&D directed toward reducing the cost of energy service in buildings, industry, transportation, and electricity supply. In each of these sectors, ORNL will be the Department of Energy's lead laboratory for development of advanced materials. In transportation, ORNL will play an important role in working with the automobile industry to develop safe, efficient, low-emission vehicles for the markets of the next century. Improved combustion, electric and hybrid propulsion systems, and intelligent vehicle technologies are areas in which ORNL technologies can be applied. Our developments in new materials and process systems will be adapted to use by several parts of the industrial sector, including turbine manufacture, pulp and paper, chemical refining, and aluminum production. The Laboratory will continue to assist suppliers to the buildings sector by developing efficient heating, ventilation, and air conditioning equipment; improved systems and materials for building envelopes, and economical building retrofit protocols. ORNL will contribute to the growing electric utility sector by developing technology for reliable automated transmission and distribution. The Laboratory's program on high-temperature superconducting materials will increasingly be directed toward practical utility and industrial applications.

To gain maximum benefit from the program, R&D activities will be carried out in close collaboration with industry through subcontracting, CRADAs, and other cooperative arrangements. Areas in which the Laboratory will strive for new or significantly expanded work include

- industrialized housing research,
- industrial chemical technologies, and
- transportation technologies.

Energy supply technology development will encompass magnetic fusion, nuclear fission, biomass, and fossil energy. ORNL will continue to play an important role in the international quest to develop magnetic fusion as a practical energy source. In particular, work will continue on advances toward steady-state confinement, applied plasma physics, plasma heating and fueling systems, first wall and blanket materials, and remote maintenance technologies. To strengthen ORNL's contributions to magnetic fusion energy development, the Laboratory will (1) pursue the restart of the Advanced Toroidal Facility (ATF) stellarator and (2) advocate the selection of an Oak Ridge site as the primary location for the nuclear technology and materials test phase of the U.S. fusion program and as this country's candidate site for the International Thermonuclear Experimental Reactor (ITER). Potential facilities at this site include 14-MeV neutron sources, such as the accelerator-based small volume source and the volumetric neutron source, for testing fusion reactor technologies and materials.

In fission energy development, ORNL will strive to be an unbiased contributor to improving the safety, proliferation resistance, economics, and environmental acceptability of nuclear electric power generation. ORNL will be the lead laboratory for reactor safety R&D in support of the Nuclear Regulatory Commission. In addition, the Laboratory will play supporting roles in other fission energy development work, including advanced reactors, high-level waste management, and accelerator-based waste transmutation.

The Melton Valley Nuclear and Radiochemical Research Center represents a major future resource for support of DOE's nuclear-related activities. The Center will consolidate both existing and planned facilities for radiochemical processing, remote materials examination, and waste

collection, handling, and packaging. These facilities will support activities such as radioisotope production and purification, radioactive waste management R&D, fuel cycle and fission product research, and R&D on decontamination and decommissioning of nuclear facilities.

The Laboratory will be an important contributor to all phases of R&D on biomass energy production, conversion, and use and will be the technical leader in feedstock production. Research will be conducted to reduce the cost and increase the productivity of woody and herbaceous biomass and to reduce the environmental and social impacts of large-scale biomass production. Advanced processes for converting biomass to end-use fuels and chemicals will also be developed. Energy applications will include transportation fuels and utility-based power generation. Emphasis will be placed on making the technologies developed in the United States available through the private sector as choices for the developing world, much of which is rich in biomass.

Work on fossil energy will emphasize improving the efficiency and the cleanliness of processes for converting and using fossil fuels. Activities will include the development of advanced materials and devices for high-temperature applications and bioprocessing for producing liquids and gases from coal and for removing undesirable materials from coal and petroleum feedstocks. The adaptation of fossil technologies to biomass will be exploited.

Environmental Technologies

ORNL will strive to be among the national leaders in the development and demonstration of advanced environmental systems. This work will be conducted in collaboration with other DOE facilities managed by Martin Marietta Energy Systems, including the Center for Environmental Technology and the Center for Waste Management, and will focus on environmental remediation and waste management at Oak Ridge sites and at other DOE sites with similar problems. The development program will include characterization and monitoring technologies, chemical and biological processing, separations science, containment and confinement technologies, robotics, risk analysis, and transportation of hazardous materials. These activities are all necessary components for ranking environmental problems that need resolution, for selecting among technology options for application to a given problem, and for implementing an appropriate technology once it is selected.

Engineering and Manufacturing Sciences and Technologies

The engineering capabilities of the Laboratory will be revitalized by upgrading the engineering R&D equipment and facilities and by developing new programs in the engineering sciences, including the traditional areas of chemical processing, solid and fluid mechanics, thermal sciences, and diffusion phenomena as well as new areas such as chaos theory, signal processing, and artificial intelligence.

A manufacturing technologies program will be developed to assist U.S. industry in becoming more competitive in global markets. This program will integrate three elements: design methods, high-performance materials and processing, and advanced manufacturing technologies. Emphasis will be on

- improved performance and quality,
- rapid transformation of concepts, technologies, and materials into high-benefit products, and
- minimizing the total life cycle cost of products.

Manufacturing R&D activities at the Laboratory will be closely linked to the Centers for Manufacturing Technology.

Physical and Materials Sciences

The Laboratory will strengthen its programs and core competencies in the physical sciences, including materials, robotics and intelligent systems, chemical sciences, and atomic, nuclear, and high-energy physics. Many of these areas of research will be profoundly influenced by the Advanced Neutron Source, which will be available shortly after the turn of the century. A detailed description of the Advanced Neutron Source appears in Sect. 4, "Summary of Major Initiatives."

Neutron-based research will be a major growth area at ORNL. Activities will include neutron scattering, materials irradiation and testing, nuclear physics, specialty isotope production for research and medical applications, and structural biology. The facilities at the High-Flux Isotope Reactor will provide the tools for neutron research during the rest of this century. Future advances in neutron-based research at ORNL and in the United States will depend heavily on the Advanced Neutron Source.

The general goal in the materials area is to strengthen our position as a world leader in materials R&D. The program will stress high-temperature materials development and solid-state physics, including surface research, preparation of new materials, advanced materials processing, and materials characterization based on neutron scattering. Materials systems to be investigated include metals and intermetallic alloys, ceramics, superconductors, composites, polymers, and semiconductors. Special emphasis will be placed on bridging the gap between basic materials research and commercial applications, with continuing development of CRADAs, licensing, and other interactions with industry. As an important part of the materials program, the Laboratory will strive to develop new and more accurate characterization and analysis facilities and will make these facilities available to researchers from industry, universities, and other Department of Energy laboratories. The Materials Science and Engineering Complex, a major Laboratory initiative planned for the late 1990s, will be especially important in fostering joint activities among various materials research groups. A detailed description of the Materials Science and Engineering Complex is given in Sect. 4, "Summary of Major Initiatives."

The Laboratory will maintain significant programs in atomic, nuclear, and high-energy physics. The atomic physics program will continue to encompass both theoretical and experimental investigations of phenomena that result when multiply charged heavy ions interact with gases, solids, free and bound electrons, photons, and other ions. In nuclear physics, the addition of the radioactive ion beam accelerator and the recoil mass spectrometer will keep ORNL at the forefront of nuclear structure research. The Laboratory's high-energy physics program is expected to grow as the result of activity in support of the national Superconducting Super Collider program. One emphasis of this work will continue to be the development of a new generation of detector systems.

A strong program in chemical sciences and engineering will be maintained, with a broad range of R&D activities including high-temperature aqueous chemistry, geochemistry, materials chemistry, actinide science, photochemistry, biophotochemistry catalysis, separation science and technology, and biochemical engineering. In analytical chemistry, new and more accurate analytical techniques will be developed to meet the research needs of the Laboratory and to provide analytical support for environmental, safety, and health activities.

The Laboratory will maintain a significant research program in robotics and intelligent systems. Autonomous capabilities and machine learning will be one area of emphasis. R&D activities will include integration of multiple data streams, decision making, modular robots, actuation in dynamic work environments, intelligent multisensor systems, and teleoperations.

Computational Sciences

Building on the excellent start provided by the ORNL basic research program in parallel computing and the new Center for Computational Sciences, an area of major growth at ORNL will be computations. The Laboratory's general goal in this field is to become one of the world's leading

centers for the application of advanced computational techniques and high-performance computing resources to problems in science and engineering. A wide range of problems will be addressed, including computational biology, plasma physics, global climate simulation, regional and local environmental modeling, first-principles simulation of materials properties, and fundamental problems in physics and chemistry. Development of visualization, networking, and systems simulations will support all of these areas. Underpinning competencies will be maintained in computer architectures, algorithm development, software tools, mathematics, and data handling and analysis.

As an integral part of its efforts in computational sciences, the Laboratory will continue to invest in improvements to the computing infrastructure. Special emphasis will be placed on data communications capabilities that will provide researchers with easy access to shared computational resources, both locally and globally.

Environmental, Life, and Social Sciences

Biological, environmental, health, and social sciences will continue to be essential components of the Laboratory's research program. The broad goal in biology is to achieve national prominence in research in molecular biology and mammalian genetics. This will be accomplished by

- strengthening the core program in structural biology,
- maintaining national leadership in protein engineering, and
- using the mouse genetics program to study genome structure and the molecular basis of human disease.

Important enhancements to the structural biology work will include the completion in 1993 of the new crystallography laboratory and increased use of the neutron facilities at the High Flux Isotope Reactor. The availability of the Advanced Neutron Source shortly after the turn of the century will add a major tool for research in structural biology. All aspects of the biology program will be greatly enhanced by the Center for Biological Sciences, proposed as a major Laboratory initiative (see Sect. 4). The Center's modern facilities will improve the Laboratory's research capabilities, and its location at the main ORNL site will facilitate interactions with the external research community.

In support of the biological and environmental missions of the Laboratory, a core program in computational bioscience will be established and conducted as a joint activity with the Center for Computational Sciences. The program will focus on high-performance computing applications in global environmental research, risk assessment, and biology.

Health and safety research will continue to focus on measuring and assessing the impacts of radiological and chemical substances on human health. Areas of emphasis will include further developing the Center for Risk Management, improving the understanding of pollutant interactions at the atomic and molecular levels, developing imaging technologies for a broad range of biological samples, creating hybrid instruments for chemical mapping, and developing advanced photonic devices for environmental and biomedical applications. Work will continue in developing radiopharmaceutical products for routine clinical applications, advancing information management techniques, and developing state-of-the-art site characterization methods and instrumentation. One major initiative is revitalizing the Laboratory's radiation dosimetry program. This effort will include establishing the Associated Laboratories for Excellence in Radiation Technology (ALERT).

The ORNL environmental sciences program will be substantially broadened in the long term to encompass research on global change, ecology, urban air quality, water resources, and environmental restoration. Global research will cover detecting, understanding, and mitigating environmental changes associated with global warming and stratospheric ozone depletion. Earth systems modeling, drawing on the Laboratory's high-performance computing resources, will become a major tool for understanding environmental change and associated ecological impacts. A special focus of the environmental program will be to make ORNL a national leader in research on the

environmental processes that govern the transport and ecological effects of pollutants resulting from the production and use of energy.

Analysis and assessment activities will continue as an integral part of the Laboratory's work on energy and environmental technologies. This work will include energy and resource analyses, assessments required by the National Environmental Policy Act (NEPA), waste management and emergency preparedness studies, transportation systems planning, and energy analyses for developing countries.

Applied research in the social sciences will continue to support the Laboratory's missions in energy and the environment. The broad goal is to make ORNL a national leader in the development and application of economic, behavioral, and social sciences to energy and environmental issues. Specific initiatives to be undertaken include

- advancing the state of the art in assessment of the environmental and social impacts of energy and waste management activities;
- initiating a program to assess and overcome the technical, economic, environmental, and social obstacles to the management of sanitary and municipal solid wastes;
- expanding work to assess the economic and social aspects of environmental externalities associated with energy and waste management technologies, and
- developing new approaches to promoting U.S. economic competitiveness in key energy and environmental industries.

Education

The Laboratory will continue its strong commitment to improving science and mathematics education in the nation's schools. The primary objective of the program is to help develop the scientific and technical talents needed to conduct the R&D required to accomplish future national objectives. The overall effort will encompass work with teachers and students at all levels, from kindergarten through the Laboratory's traditional involvement as a resource for undergraduate, graduate, and postgraduate study and faculty research. Special attention will be given to the design, development, and delivery of comprehensive programs for elementary and secondary teachers and students. Partnerships with other organizations (the Appalachian Regional Commission; schools, colleges, and universities in the state and the region; the private sector) will be the principal mechanism for educational activities. These partnerships will involve a major new emphasis on the application of computing and communications technologies to education.

Strategic Objectives

The vision and research directions outlined for the Laboratory portray many areas of significant change over the planning period. Bringing these changes about will require important commitments of resources and management attention. Some of these areas, because of their importance or the difficulty of accomplishing them, will require special attention. Here we present those areas as strategic goals, divided into two categories: programmatic goals, associated with specific program areas, and institutional goals that deal with Laboratory-wide issues.

Programmatic Goals

- **To become a world leader in neutron-based R&D.** Neutron-based R&D has strong historical roots at the Laboratory and is critical to future advances in many areas of science and technology, including materials, medicine, energy technology development, nondestructive testing, and structural biology. For three decades, the High Flux Isotope Reactor at ORNL has supported neutron-based R&D with outstanding facilities for neutron scattering, isotope production, and

materials irradiation. This reactor is nearing the end of its useful life and has been surpassed by newer facilities in other countries. Construction of the Advanced Neutron Source is the key to achieving the goal of regaining world leadership in neutron-based R&D.

- **To achieve national prominence in biotechnology.** The Laboratory will develop an integrated program in biotechnology that spans the range from basic research in molecular biology to applications in bioprocessing and environmental biotechnology. In molecular biology, the record of excellence in mouse genetics and protein engineering will continue, and a strong program in structural biology will be developed. Work in bioprocessing will include bioconversion of coal to high-quality fuels and waste stream processing. Activities in environmental biotechnology will include biomarkers, biomonitoring, and bioremediation. The additional research capabilities that will be provided by the Center for Biological Sciences will be crucial to achieving the goal of gaining national prominence in biotechnology.
- **To strengthen ORNL's position as a world leader in materials R&D.** The Laboratory is already recognized for its excellence in materials. Work in materials science and engineering underpins a large portion of ORNL's energy technology programs and provides a substantial base for interactions with industry. Further strengthening of this program will require a broadening of core competencies in the materials area and the addition of new research facilities, the most important of which are the Advanced Neutron Source and the Materials Science and Engineering Complex.
- **To become one of the nation's premier centers for applied computational sciences.** We strongly believe that, in the future, excellence in research will require excellence in the computational sciences. The ORNL Center for Computational Sciences gives the Laboratory a strong start toward this goal. We will build on this start by making numerical simulations an essential element of every R&D program at the Laboratory.
- **To become a leading laboratory for transportation technologies.** ORNL has excellent programs in some areas of transportation, especially in advanced materials for vehicles, in transportation of hazardous materials, in military logistics, and in traffic analysis and emergency response planning. To reach the goal of becoming an important center for transportation R&D, we will broaden the research agenda to include stronger programs in advanced internal combustion engine technology, electric and hybrid vehicles, intelligent vehicles and highway systems, and automotive manufacturing. The manufacturing initiative is a collaborative effort with the Department's Oak Ridge Y-12 Plant.
- **To become an international leader in the development of biomass energy technologies.** The Laboratory has made a good start toward this goal through its solid program on biomass production. Becoming an international leader will require that we strengthen our research and technology transfer activities on (1) converting biomass to end-use fuels and chemicals; (2) ameliorating the environmental and social impacts of the large-scale, managed production of biomass; and (3) moving technologies from the laboratory to practical uses throughout the world.
- **To become a world leader in global change R&D.** ORNL's program in global research, which covers both global warming and stratospheric ozone depletion, consists of a broad activity base that is evolving toward a world-class program. We will build on the existing activities to develop a comprehensive set of core competencies in global change research.
- **To become an important contributor to improving the nation's competitiveness in manufacturing.** In cooperation with the Oak Ridge Y-12 Plant, the Laboratory will develop an integrated program focused on design techniques and manufacturing technologies for products that use advanced materials.
- **To be the site for the nuclear phase of magnetic fusion R&D.** The Oak Ridge area would be an excellent choice for the primary site of the nuclear technology and materials test phase of the U.S. fusion program and for the U.S. candidate site for ITER.
- **To establish in Melton Valley one of the nation's leading centers for nuclear and radiochemical research in the 21st century.** The Melton Valley Nuclear and Radiochemical

Research Center will be an important national facility for neutron-based R&D, isotopes production, radiochemical processing, remote handling, and waste management. When fully developed, the Melton Valley facilities will include the Advanced Neutron Source, the Waste Handling and Packaging Plant, a radioactive materials packaging and shipping facility, "hot" facilities for chemical and multipurpose use, and a nuclear training center. This combination of capabilities will make the Melton Valley Center a unique national resource.

- **To revitalize engineering R&D at ORNL.** Research activities in the engineering sciences will be expanded, and engineering R&D equipment will be upgraded. We believe the future of the Laboratory is closely linked to our ability to maintain excellence in the engineering disciplines.
- **To be recognized as an important center for the development of environmental technologies.** Work in support of this goal, which will emphasize improved technologies for environmental remediation and waste management, will be a collaborative endeavor with other DOE facilities managed by Martin Marietta Energy Systems.
- **To become a leading laboratory in R&D directed toward worldwide sustainable development.** The focusing theme of all of the Laboratory's energy and environmental programs will be to develop and implement technologies that will enable the world to meet its energy needs in ways that are sustainable, both economically and environmentally. An important emphasis will be on the developing countries.

Institutional Goals

- **To attract and retain the very best staff.** The future of ORNL, like that of most institutions, lies largely in the hands of its staff. To achieve our challenging programmatic goals, we will continue to emphasize excellence in the staff. In the face of growing competition, we will work to attract and retain the kind of people ORNL needs, seeking out the best from all elements of American society. The natural consequence will be a culturally diverse staff. In addition, we will work to stay competitive in many areas, including compensation, benefits, recognition, and educational opportunities. Probably most important in attracting and retaining excellent people, we will provide the opportunity to do great work with great workers.
- **To provide greater intellectual leadership in shaping the national agenda for energy and environmental R&D.** The Laboratory has a large, diverse research staff that is well versed in many fields of science and technology. This important resource will be used more effectively to give our sponsors and the nation objective advice and innovative ideas about energy and environmental needs and opportunities and about policy options. As part of this goal, more emphasis will be placed on understanding the social and environmental consequences of energy production and use and on explaining these consequences to the American public.
- **To revitalize the infrastructure of the Laboratory.** A major effort will be made to upgrade the Laboratory's general-purpose facilities. Maintenance activities will be made more effective, substandard structures will be upgraded or torn down, and new office space will be added to accommodate ORNL staff and the increasing number of guests. An important emphasis of the infrastructure revitalization will be improvements that maintain a safe and healthy workplace and protect the environment.
- **To be recognized as a technology transition laboratory.** We are firmly convinced that the future of DOE's laboratories lies in a closer partnership with many elements of American society. Our goal is to become known as (1) the place to go to collaborate with world-class researchers in a variety of fields, (2) the place to go to use state-of-the-art research facilities, and (3) the place that works most effectively with industry to move new technologies from the laboratory into the marketplace.
- **To become known as a place that gives top value for the research dollar.** In making our operations more efficient and more effective, we will focus on (1) reducing the cost of doing business, including overhead burden and construction costs, (2) improving teaming between the

research staff and the support staff, and (3) empowering Laboratory staff and reducing bureaucratic impediments to getting things done.

Strategic Issues

The Laboratory's strategic goals are quite aggressive and will be very challenging, but we believe that they are achievable. Specific strategies are being developed for each goal. Some high-level strategic issues are summarized here.

Of the strategic issues that stand between the present and a successful future, two of the most important are as follows.

- **Limited resources.** All of the programmatic goals require resources of one kind or another, either from inside the Laboratory or from the Department of Energy or other sponsors. Nationally, the federal budget deficit will be a constraint on new initiatives for several years to come. The Department must deal with many high-priority topics, such as environmental restoration and the creation of new and expensive world-class research facilities, and this will simply make it impossible for the Department to support everything. Within the Laboratory, time is a limited resource; it must be split between things that are important (like moving the Laboratory toward its strategic goals) and things that are simply urgent. The Laboratory Directed R&D Program is another internal resource that is very important in moving ORNL in new directions; it is also a limited resource that must be spread over a number of new research ideas and initiatives.
- **Needs of the Department of Energy and its laboratory system.** The events of the past few years, including the end of the cold war, are requiring the Department to rethink its roles and responsibilities and those of its laboratories. Clearly, all components of the system must work more closely together—more cooperation and collaboration and less duplication of research capabilities. Thus, ORNL's strategic directions must be compatible with those of the Department and the laboratory system.

Strategies

The problem of limited resources will be dealt with through a number of techniques. First, a priority system will be used to assign resources to achieving the Laboratory's strategic goals; the priority process will assist in allocating both funds and time. Second, action plans will be used to provide clear responsibilities for achieving each strategic goal; by distributing authority and responsibilities widely throughout the Laboratory, senior management's time will be substantially leveraged. Last, we will simply have to work smarter—focus on the truly important and use resources wisely.

The issue of making the Laboratory's strategic goals consistent with, and supportive of, the strategic needs of DOE and its laboratory system will require strong involvement and leadership on the part of the laboratory directors. The laboratory directors are engaged in cooperative activities that will be very effective in strengthening the laboratory system. These include task forces on economic competitiveness, public outreach efforts, and combined groups to define missions, goals, and core competencies.

4 • Summary of Major Initiatives

The ORNL Research and Development (R&D) Strategic Planning Committee has chosen 11 major initiatives for the Laboratory. Three of these are continuing initiatives of the highest priority:

- the Advanced Neutron Source,
- High-Performance Computing R&D, and
- the Center for Biological Sciences.

Other continuing initiatives, presented in alphabetical order, are

- Advanced Materials, Design Methods, and Manufacturing Technology,
- Biotechnology,
- the Environmental, Life, and Social Sciences Complex,
- the Materials Science and Engineering Complex,
- Oak Ridge as a National Fusion Nuclear Site, and
- Transportation Technologies and Systems.

Two new initiatives are proposed:

- the Center for Environmental Technology and
- Energy and Environmental R&D for a Sustainable Future.

Other programmatic initiatives are listed at the end of this section and described in detail in Sect. 5, "Scientific and Technical Programs," under the programs from which funds are sought.

These initiatives are provided for consideration by DOE. Inclusion in this plan does not imply DOE approval of, or intent to implement, an initiative. Resource projections (Sect. 11) do not include funding for new initiatives.

Advanced Neutron Source

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

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

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

To achieve the project's performance criteria, a small, high-specific-power reactor design (cooled, reflected, and moderated by heavy water) has been devised. As with DOE's Advanced Power Reactor Program, maximum use has been made of passive safety features. Other safety-related design features include two independent, diverse, and redundant shutdown systems. In addition, the reactor is placed in a large, double-walled containment building.

Corrosion of aluminum alloy fuel cladding may pose temperature and structural problems associated with the formation of an oxide layer during the lifetime of the core. Earlier research, mostly in support of the HFIR and the Advanced Test Reactor designs, indicated that under extreme heat-transfer conditions the exposure of aluminum and many aluminum alloys to water leads to the growth of an adherent oxidation product of significant thickness. At the high heat flux levels expected in the ANS core (6 to 11 MW/m^2), interspersing an oxide film of low thermal conductivity between the fuel plates and the cooling water may in certain instances lead to plate overheating. To ensure that the integrity of both the fuel and the cladding is maintained under the unique conditions imposed in the ANS fuel plates, an experimental facility was constructed to allow detailed study of this type of corrosion behavior for a wide range of thermal-hydraulic conditions.

The Corrosion Test Loop Facility has been in virtually continuous operation since January 1988. A forced-flow water loop fabricated entirely of type 304L stainless steel components operates at pressures up to 7 MPa. The loop is completed by a specimen of the sample aluminum alloy in the form of a tube enclosing a rectangular flow channel with the same narrow dimension (1.27 mm) as the gap between ANS fuel plates. The overall channel dimensions allow tests up to coolant velocities of 30 m/s at the maximum flow rate (2 L/s). The specimen is welded to large electrodes, installed in the main section of the loop, and surrounded by electrical and thermal insulation and pressure backing. The heat flux (up to 20 MW/m^2) is produced by Joule heating of the specimen with a 30-kA dc power supply; downstream of the specimen, the heat is removed by a water-cooled heat exchanger. A low-pressure bypass (cleanup) line is used in the same way as in a typical reactor to permit instrumentation and to provide water chemistry control within the loop, principally by deionization followed by pH control using nitric acid addition. In addition, a thermal-hydraulic test loop is being used to verify the correlations used to establish critical heat flux, flow stability, and other parameters determining the safety margins. This is needed because of the sparse experimental data for the high heat flux and coolant velocity expected in the ANS reactor core.

The ANS conceptual design has been completed. The conceptual design report, issued in June 1992, contains definitions for and documentation of a reference design for the primary and secondary cooling systems and conceptual designs for the layout of the experimental and operational equipment and space requirements and for the detritiation/heavy water upgrade plant. Preparation of the Environmental Impact Statement has started and will be completed when the Record of Decision is issued in FY 1995.

The project schedule calls for reactor startup in FY 2002, which approximately coincides with the estimated end of useful life for the existing reactors. Design and construction of a reactor that will meet all of the performance criteria are considered feasible. Design will proceed at a controlled pace to allow for resolution of the remaining uncertainties.

Budget projections for the planning period are given in Table 4.1. The ANS is supported through the DOE Office of Basic Energy Sciences (DOE-BES) and is managed by the DOE Office of Nuclear Energy (DOE-NE).

Table 4.1
Budget projections by fiscal year for the Advanced Neutron Source
($ in millions—BA)[a]

	1993	1994	1995	1996	1997	1998	1999
Operating expense	20.6	12.0	46.8	45.9	45.9	36.9	55.1
Capital equipment	0.9	1.0	4.4	4.2	3.5	3.0	1.5
Construction line item	—	26.0	88.3	164.6	317.2	471.1	474.8
Total	21.5	39.0	139.5	214.7	366.6	511.0	531.4

[a]Actual dollars.

High-Performance Computing R&D

With the national High Performance Computing and Communication (HPCC) initiative, U.S. leadership in high-performance computing was imaginatively extended. To implement this initiative, DOE established two High-Performance Computing Research Centers (HPCRCs), one at ORNL and one at Los Alamos National Laboratory (LANL). The HPCRC at ORNL is situated within the Center for Computational Sciences (CCS), which has responsibility for

- conducting research in the "Grand Challenge" areas of groundwater transport and remediation, materials simulation, and global change as represented by DOE's Computer Hardware, Advanced Mathematics, and Model Physics (CHAMMP) program;
- providing a computing center capable of meeting program requirements, using Intel Paragon and Kendall Square massively parallel processing (MPP) computers and incorporating state-of-the-art peripherals (e.g., storage and backup systems);
- providing an effective and stimulating computing and research environment for all Grand Challenge research groups using our machines;
- evaluating developing computing systems, procedures, and architectures;
- developing and providing advanced networking; and
- conducting the Adventures in Supercomputing (AiS) educational program.

Budget projections for the CCS are shown in Table 4.2.

Table 4.2
Budget projections by fiscal year for the Center for Computational Sciences[a]
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Operating expense	13	18	19	23	24	26
Capital equipment	2	2	36	3	3	2

[a]Funding is being sought from the Office of Energy Research.

The research and educational programs of the CCS are carried out by the Partnership in Computational Science (PICS) consortium established for this purpose. Members of the consortium, in addition to ORNL, are DOE's Ames Laboratory, Sandia National Laboratories–New Mexico, and Brookhaven National Laboratory; the State University of New York at Stony Brook; the University of

South Carolina; the University of Tennessee at Knoxville (UTK); Vanderbilt University; Rice University; and Texas A&M University. The programs of the CCS are closely coordinated with those of the Advanced Computing Laboratory at LANL to ensure the success of the HPCC initiative.

Grand Challenges

As defined by the Federal High Performance Computing Program, a Grand Challenge is "a fundamental problem in science or engineering, with a broad application, whose solution would be enabled by the application of the high performance computing resources that could become available in the near future."

Groundwater Transport and Remediation

The goal of the PICS groundwater group is to develop and test a parallel, three-dimensional code, incorporating both flow and transport, that accounts for all of the complex processes involved—front-tracking, bioremediation, radionuclide decay, multiphase flow, and chemical reactions and kinetics.

Some of the leading groundwater modelers in the United States are participating in the groundwater group. Substantial progress has been made in using parallel codes describing flow and transport independently, with the linking of the two processes now under way. As additional physical and chemical processes are incorporated, the computing demands will intensify. The computing power of the CCS will be an essential element in dealing with the huge arrays of nonlinear equations.

The principal site being modeled, and against which the code will be tested, is Waste Area Grouping (WAG) 6 in Melton Valley at Oak Ridge. Some preliminary results have been obtained. Available topographic data have been incorporated into the code, and initial studies of capping results have been made.

While some of the computational improvements required to solve these problems will come from the availability of higher performance computers, an equally important source of improvements will be new parallel algorithms and mathematical strategies. Thus, mathematicians and mathematics play critical roles in this work.

Materials Simulation

The capability to design materials with specific and well-defined properties is an essential component of the nation's technological future. The central goal of the materials simulation Grand Challenge is to investigate new methods for performing large-scale simulations of materials properties, using a hierarchy of increasingly accurate and computationally intensive techniques: classical potentials, tight-binding models, and ab initio methods. Several of these methods seem particularly attuned to adoption on MPP computers, and their successful implementation would be a giant step toward the overall scientific goal of understanding, predicting, and designing materials with specific properties.

The target is the accurate treatment of large collections of atoms (100,000 or more for classical potentials, 10,000 for tight-binding, 500 for first principles) and evaluation of all aspects of their interactions. This so-called "mesoscopic" regime holds the key to understanding and quantitatively studying many important materials phenomena (e.g., phase transformations, grain boundaries, dislocations, relaxation around impurities, disorder, and melting). Our long-range goal is to develop techniques that will make it possible to perform calculations that accurately describe these phenomena, so as to understand and eventually control various parameters relevant to technologically important applications. The use of parallel processing techniques to develop efficient scalable

strategies will allow us to solve materials problems that are beyond the range of current first-principles methods.

Specific problems now under investigation include alloy phase stability (Pd-Rh, Al-Mg, Al-Li), magnetic phase transitions, fullerene character and synthesis, melting, dislocation structure and dynamics, and photonic band structure. Here, as in the groundwater project, algorithm development and improved computational techniques play critical roles in making physically meaningful solutions possible.

Global Change

Parallel processing in climate modeling has been recognized as the means to greater throughput and enhanced representation of key climate processes. The resolution of features on a regional scale and the representation of clouds, radiation, and terrestrial and oceanic processes as a closely coupled climate system require computing power in the range of trillions of floating point operations per second (teraflops).

The goal of the CHAMMP Program is to provide climate researchers with an advanced modeling capability for the study of global change issues. As a first goal in the program, state-of-the-art models are being implemented on MPP computers, allowing an increase in spatial resolution and faster turnaround time for climate studies. Accomplishment of this task will lay the groundwork for the second goal of the program, which is to develop more comprehensive models of climate dynamics using coupled atmospheric and oceanic global climate models with improved accuracy.

Researchers at ORNL, Argonne National Laboratory, and the National Center for Atmospheric Research (NCAR) are collaborating to address the problems of modeling the atmospheric component of the climate system on parallel computers. This work is focused on making the NCAR Community Climate Model (CCM2) available on the CCS computers. A production version for the Intel Paragon system is under development. With even moderate resolution, 10- to 100-year simulations using the CCM2 produce voluminous output—on the order of 200 gigabytes. Thus, the input/output (I/O) must be optimized for parallel execution and analysis, as a key element in production use.

Advanced Technology

The Intel Paragon Computers and the CCS Staff

The calculations and modeling necessary to ensure progress on the Grand Challenge problems demand, and in some circumstances exceed, the state of the art. Thus, the CCS computers must represent the state of the art. This fact is embedded in the center's current plans and long-term goals.

Our computing plan features a sequence of Intel Paragon XP/S computers (in the designation XP/S *n*, the *n* represents the nominal peak speed in billions of floating point operations per second or gigaflops):

Machine	Operational
XP/S 5	May 1993
XP/S 35	September 1993
XP/S 75	December 1993
XP/S 150	September 1994

The XP/S 35 and 75 will be removed near the end of calendar year 1994. This sequence of machines, placing ORNL at the forefront of high-performance computing, will provide PICS and CHAMMP

scientists with an opportunity to build and test codes and then to carry out huge production runs on machines of increasing power.

To ensure reliable computing resources to Grand Challenge users, the CCS includes a user services staff, in addition to an operations and administrative staff. Industrial participation, an important aspect of the CCS, includes a cooperative research and development agreement (CRADA) that supports the full-time presence of three parallel systems engineers from Intel.

Given the power of the machines that will soon be operating, the storage and backup requirements will greatly exceed the available capacity. The CCS staff is working closely with scientists in the ORNL Environmental Sciences Division to define these requirements. The CCS and the Atmospheric Radiation Measurement (ARM) Program will join forces to create a multi-terabyte, high-performance file storage system that will meet the data storage needs of both. (For a detailed discussion of the ARM project, see Sect. 5, "Scientific and Technical Programs.") This file storage system will house a complete data archive for the ARM project and meet the data archival needs of the CCS. The anticipated storage requirements of the CCS are 0.5 terabyte in FY 1993, 2.5 terabytes in FY 1994, and 5.0 terabytes in FY 1995.

Our current plan is to share the cost of the archive between the ARM project and the CCS, based on the storage requirements of each project. Our capital requirements include devices providing capability to perform system backups effectively and with reasonable speed and to offload large files from the Paragon systems to a backup tape device.

One of the key expectations of the CCS is maintaining forefront computing character. This requires the projection of computing capabilities beyond those in the current plan. We intend to carefully assess the directions of supercomputing over the next two years and then propose to DOE the procurement of a computing capability exceeding 300 gigaflops toward the end of FY 1995. While this could be another Intel machine, our planning will not be restricted to any single supplier. The emergence of advanced versions of the distributed computing system PVM from ORNL may point to alternative strategies for obtaining the requisite computing level.

Evaluation of Developing Systems

The Evaluation of Developing Systems Project investigates new and experimental computer systems, focusing on innovative hardware and software features, to evaluate their suitability for Grand Challenge applications and to provide feedback to machine architects, system software designers, and application programmers. The project comprises four activities: acquisition, beta testing, benchmarking, and modeling

As our sophistication in the parallel processing realm grows, systems and strategies requiring development and evaluation emerge. Some of these, such as performance monitoring systems, debugging aids, and scheduling algorithms, are less conspicuous than the highly visible areas of storing and efficiently accessing enormous data sets, networking, and visualization, but are nonetheless of prime importance.

We will work with our Intel machines and with Intel, as well as with other vendors, to develop and evaluate performance monitors, debugging aids, and scheduling algorithms. The enhanced CCS/ARM storage and backup systems will also provide opportunities for evaluating these systems and effective strategies in using them. However, these systems will be centered on production, so they do not represent an experimental environment. Accordingly, we will acquire, construct, and evaluate a next-generation heterogeneous distributed computing system. This integrated system will comprise prototype high-performance workstations and networks, as well as a high-density data storage archive. Some or all of the workstations will have full multimedia capabilities, including video output. Our evaluation of and experiments on this system will proceed along three fronts:

- Storage—evaluating solutions to the massive data storage and archive problems presented by the Grand Challenges and investigating the issues of integrating large multimedia databases into a distributed computing environment.
- Visualization—evaluating the viability of interactive visualization of Grand Challenge output, allowing researchers to ask "what if?" and then steer the simulations to interesting solutions. We will evaluate the use of multimedia to explore massive data sets in an attempt to provide guidance toward discovering interesting, important, and perhaps subtle scientific phenomena.
- Computing—evaluating the performance and capabilities of the next generation of hardware for distributed computing, with special emphasis on the effective use of large distributed databases and network transfer problems.

The estimated system cost is in the range of $1 million, with roughly half used to purchase the prototype workstations and high-speed network interfaces. The number of machines to be acquired will depend on negotiations with the vendors and will include the option of CRADAs. The remaining funding will be used to purchase a large data storage device that will be integrated into the heterogeneous cluster, as well as made available for use by the CCS computers.

Networking

The Evaluation of Developing Systems Project includes plans for a laboratory with the capabilities to explore innovations in networking that will move us into the gigabit per second region and beyond. Recognizing that first-quality networking is the key to many aspects of our computing and communications future, we also emphasize the availability of "operating" networks for the CCS and for our PICS and CHAMMP participants.

We intend to create an experimental, high-speed network between ORNL and our sister HPCRC laboratory, LANL. The specific purpose is to explore a heterogeneous, distributed supercomputing system, made up of the Intel Paragons at ORNL and the Thinking Machines CM5 at Los Alamos.

We will base this network on the Cross Bar Interconnect (CBI) technology developed at Los Alamos, which allows the "striping" of a standard HiPPI channel across multiple OC3 SONET connections. SONET equipment is being installed at ORNL by Bell South through a CRADA arrangement. Similar SONET gear is being installed by US West at Los Alamos to support the CASA network termination there.

Our initial estimate is that a network based on multiple OC3 circuits would cost on the order of $1.5 million per month. We propose to reduce this cost by making the network available for no more than several hours a day and identifying industrial partners interested in exploiting the opportunities that such a network would provide. Indeed, the opportunity to use this network for real-time applications, as well as studies of network-based database manipulation, could make such an arrangement attractive.

If the CBI approach to building the ORNL/LANL network is used, a natural extension of the basic concept would be to interconnect this network with the CASA network. This would effectively link all of the major DOE computing facilities in a single gigabit network. We are pursuing and contemplating additional important networking experiments and strategies. As emphasized, state-of-the-art networking is essential to the proper functioning of the CCS. Our strategies incorporate this requirement, and our programs include a leadership component in the networking realm.

Adventures in Supercomputing

The Adventures in Supercomputing (AiS) program was designed to cultivate the interest of female, minority, and disadvantaged students, from the elementary level through high school, in science, mathematics, and computing. The program's initial focus has been at the high school level.

The ability of the United States to compete in world markets increasingly depends on our ability to identify and train scientists and engineers. While the demand in these areas is great, the traditional pool of prospective technologists—white males—continues to shrink as a percentage of the work force. In addition, the number of technically literate citizens continues to be insufficient.

To address these problems, the AiS program has developed an approach that combines a number of mutually supporting elements.

School selection. High schools in each participating state apply to the AiS program. Schools are chosen by a selection committee on the basis of their ability to reach women, minority, and disadvantaged students and their ability to implement the program.

Teacher curriculum. During the summer, AiS teachers attend a 13-day Summer Institute, which familiarizes them with computer techniques and prepares them to lead AiS classes. The AiS curriculum is based on a successful program in Alabama, initiated in 1989 by Prof. John Ziebarth of the University of Alabama at Huntsville. Two one- or two-day teacher workshops are held during the school year, and an Advanced Summer Institute is held at the conclusion of the first year.

Supercomputer access. The participating DOE laboratories provide access to an nCUBE parallel supercomputer to students and teachers in the AiS program.

Internet access. Each school has direct access to the Internet via a 56-kilobit/s leased line. Students use the Internet to locate information and potential mentors.

Equipment in schools. Each school is loaned one color printer and four Macintosh systems with color monitors. Software is provided to enable programming and scientific visualization.

Continuing technical support. Graduate students provide on-call technical support.

Student projects. During the school year, students develop computational science projects. These are exhibited at an exposition in each state in the spring.

Assessment. An in-depth, continuing assessment of the program is being conducted to evaluate both the successes and failures of all of its aspects.

The AiS program was instituted in 1992 as a five-year pilot project, hosted in Iowa by Ames Laboratory, in New Mexico by Sandia National Laboratories–Albuquerque, and in Tennessee by ORNL. The early successes of the program have encouraged DOE to extend it; Colorado and Alabama are now participating. Thus, the number of high schools in the program—20 in 1992—is increasing to roughly 50 during 1993. An effort has begun to develop an appropriate curriculum to extend AiS downward to the junior high school level. Also, an experiment is in progress to use UNIX workstations directly in the schools.

Industrial Participation

Industrial participation is a central feature of the HPCC initiative and the CCS. We have strong ties with the computer industry. Through extensive efforts, particularly in the ORNL Metals and Ceramics Division, the CCS has established a wide range of industrial contacts, some of which have led or are leading to CRADAs. Our focus now is to achieve similar successes in the environmental area. We will work to find and establish mechanisms through which we can assist American industry in work that requires computing capabilities of the type and power found in the CCS.

Center for Biological Sciences

A number of national-level assessments have singled out the life sciences as a key area of scientific growth for the United States. The Report of the National Critical Technologies Panel in 1991 stated that "the life sciences advances have led to the development of recombinant DNA

techniques, monoclonal antibody technology, sophisticated new approaches to bioprocessing, and other biotechnological applications with almost limitless potential to benefit mankind." The Committee on Life Sciences and Health of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) stated in February 1992 that the United States "has been the world leader in biological research for the past 30 years" and that this leadership "is clearly being challenged as the field changes and expands rapidly."

The National Energy Strategy (NES) identifies biology and life sciences as areas of fundamental science that are particularly important to achieving the nation's energy goals. The NES further identifies several important areas of biological and life sciences research, including (1) basic research on how the structures of proteins determine their functions in living cells; (2) the development of new genetic stocks of plants with improved characteristics for biomass conversion; (3) the development of microorganisms tailored to the fermentation of biomass to fuels; and (4) the human genome. Biotechnology and the human genome are two of the fastest growing areas in the DOE life sciences.

For more than four decades, the ORNL Biology Division, located at the Oak Ridge Y-12 Plant, has steadily expanded the frontiers of life science: first, by illuminating the biological effects of radiation; later, by pioneering methodologies for radiation and chemical risk assessments; more recently, by exploring the most basic life processes, including genetic replication and repair, and protein structure/function relationships.

Today, ORNL is conducting a wide variety of research activities that support the biological and life sciences goals of the NES and that are called for in other national assessments. The Biology Division is one of the largest of DOE's life sciences research laboratories. Its research areas include protein engineering, structural biology, genome research, and chemical and radiation mutagenesis and carcinogenesis. The division's mouse genetics research program is unique in scope among government agencies and universities, and it complements human chromosomal mapping studies at other DOE laboratories; the division's collection of about 250,000 mice serves a worldwide community of users from academia, industry, and other research institutions. Also, among DOE laboratories, ORNL's Biology Division has the only formal program in protein engineering. The division continues its record of distinguished research in today's changing climate and remains a vibrant, highly productive research organization. The division supports about 115 full-time research and support personnel. About 200 stafff members in other ORNL divisions also contribute to biological sciences research. The total annual funding for all biological science at ORNL is about $30 million (all funding sources).

The potential contribution that the division can make to the life sciences is severely and increasingly constrained by the antiquated condition of its research facilities, most of which are now half a century old. As the building systems age, increasing amounts of research funding must be used for maintenance, utilities, and environmental, safety, and health (ES&H) protection. Since these facilities were built, major advances have been made in facility design. It is now possible to construct more cost-effective biological facilities that also meet all new standards for ES&H compliance.

To provide a facility that will promote and enhance the future research goals of the Biology Division, a Center for Biological Sciences (CBS) is proposed for the West End of ORNL as part of the Environmental, Life, and Social Sciences Complex, discussed later in this section. The CBS will be a 250,000-ft^2, two-story structure (with a basement) and will be of steel frame and masonry construction. Its modular design features a central core that contains research and support functions and wings that house animal and laboratory facilities. The proposed site is located 0.25 miles northwest of the existing Building 1505 (occupied by ORNL's Environmental Sciences Division). Figure 4.1 is a conceptual drawing of the proposed building.

The building will be zoned by functions and arranged to provide high-efficiency operations. Functional areas include (1) animal facilities for housing and caring for a diversity of mouse genetic strains, including animal rooms, cage- and bottle-washing stations, and feed and bedding storage;

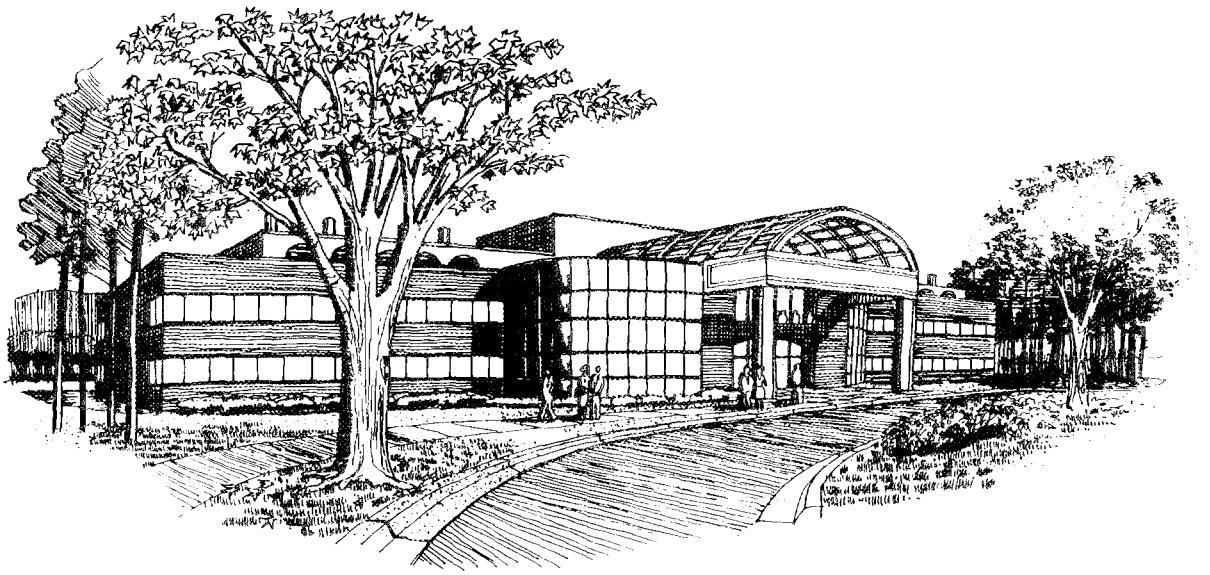

Figure 4.1
The proposed Center for Biological Sciences.

(2) biochemical research space for conducting mammalian genetics, cancer biology, molecular genetics, structural biology, and protein engineering research, including laboratories, equipment space, and office space for scientists, technicians, guests, and students; (3) the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences; and (4) administrative operations such as library, computer center, and division administration. About 60% of the research areas will be assigned to principal investigators, and the remaining 40% will be available for shared equipment or special purposes.

A wide diversity of special facilities required by the ORNL Biology Division will be integrated into the building in an efficient and a cost-effective manner. Examples include areas suitable for gamma and X-ray irradiation, barrier areas for working with specific pathogen-free animals or hazardous materials, darkrooms, electron microscopy facilities, environmentally controlled rooms, tissue culture areas, and glassware kitchens. The facility's mechanical systems will provide efficient use of energy and a suitable environment for animals, research, and the research staff. Telecommunications equipment will include standard voice and data communications and will support the growing worldwide user community of the Gene Recognition and Analysis Internet Link (GRAIL), a system jointly developed by the ORNL Biology and Engineering Physics and Mathematics divisions. Facility-related costs for maintenance and utility services and for ES&H protection will be significantly lower in the new facilities than in the current site, thus releasing operating funds for research.

The proposed CBS is central to ORNL's pursuit of excellence in biological research and its growing involvement in biotechnology. State-of-the-art facilities will enhance ORNL's ability to effectively compete with other research institutions in attracting the outstanding young scientists required for an institution to maintain scientific leadership. These scientists represent the future research potential needed to achieve the biological and life sciences research goals set forth in the NES. This includes not only potential new ORNL employees and post-doctoral staff, but also

graduate students at the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences, which is a long-standing collaborative effort that has trained some of the nation's finest biologists.

The new facilities will enhance interactions between Biology Division staff and other researchers in the scientific community, thereby providing a potential "multiplier" to the scientific value of life sciences research funding at the Laboratory. The relocation of the division to the main ORNL site will enhance its ability to collaborate scientifically with other ORNL life sciences divisions and to interact effectively with major ORNL facilities that will enhance the breadth and scope of the Division's research, such as HFIR, the ANS, and the Center for Computational Sciences. The Division's current 13-km (8-mile) separation from ORNL is a serious impediment to these collaborations, as are the restrictions to access by visiting scientists that stem from the Division's current location at the Oak Ridge Y-12 Plant.

The CBS will provide user facilities for guest scientists in areas such as structural biology, "transgenic" mouse production and breeding, understanding the genetic basis of human disease, and mapping and engineering of macromolecules. These facilities, coupled with the location at the main ORNL site, will further enhance collaborations and technology transfer and will facilitate implementation of CRADAs.

FY 1994 funding is being sought from the Office of Health and Environmental Research (OHER). The total estimated cost of the facility is $98.7 million. The total project cost is about $99.7 million. Table 4.3 provides additional budget information about the CBS.

Table 4.3
Budget projections for the planning period by fiscal year for the Center for Biological Sciences
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Operating	0.4	0.1	0.1	0	0	0
Construction line item	0.0	16.0	42.0	40.7	0	0
Total	0.4	16.1	42.1	40.7	0	0

Physical construction is planned to start in the fourth quarter of FY 1995 and end in the fourth quarter of FY 1998. Relocation of the Biology Division staff and equipment to the new facility would begin in late FY 1998 or early FY 1999.

In late FY 1992, OHER provided operating funds to begin pre–Title I activities and other planning tasks for the CBS. Activities conducted to date include initiating the preparation of National Environmental Policy Act (NEPA) documentation, preparing the Security Plan, completing the Safety Assessment, and initiating an update of conceptual design information. In early FY 1993, OHER identified the CBS as its foremost long-term facility need. Also in early FY 1993, Martin Marietta Energy Systems identified the CBS as one of its six critical initiatives. State and local governments, the University of Tennessee, and other key organizations have been briefed on the CBS. A Field Work Proposal (FWP) has been submitted to OHER for additional FY 1993, FY 1994, and FY 1995 operating funds to complete the necessary preliminary documentation and line-item support.

The CBS is a key facility for achieving the life science goals of the NES. With its promise of novel approaches to conquering disease, easing world hunger, and reducing environmental pollution, biotechnology may set in motion the greatest scientific revolution in human history. By consolidating and expanding ORNL's research expertise and unique resources, the CBS can help accelerate that revolution. By decoding the biochemistry of human genes, probing and reshaping proteins, and

developing new biotechnology for medicine and industry, ORNL researchers will continue to unlock the complex biological secrets of life and health.

Advanced Materials, Design Methods, and Manufacturing Technology

Manufacturing high-quality products that are affordable and provide benefits to the consumer is central to restoring the nation's economic vitality. Today, the U.S. manufacturing base represents nearly 25% of the gross national product and accounts for about 17% (over 20 million) of the nation's jobs. To strengthen this manufacturing infrastructure and create high-value jobs that improve both the local and the national standard of living, special attention must be focused on R&D and application of advanced technologies and engineering concepts for manufacturing. Design, materials, and manufacturing are key elements in the successful development of high-performance products. Figure 4.2 compares the ideal integration of these elements with a more typical approach of limited interaction and even isolation.

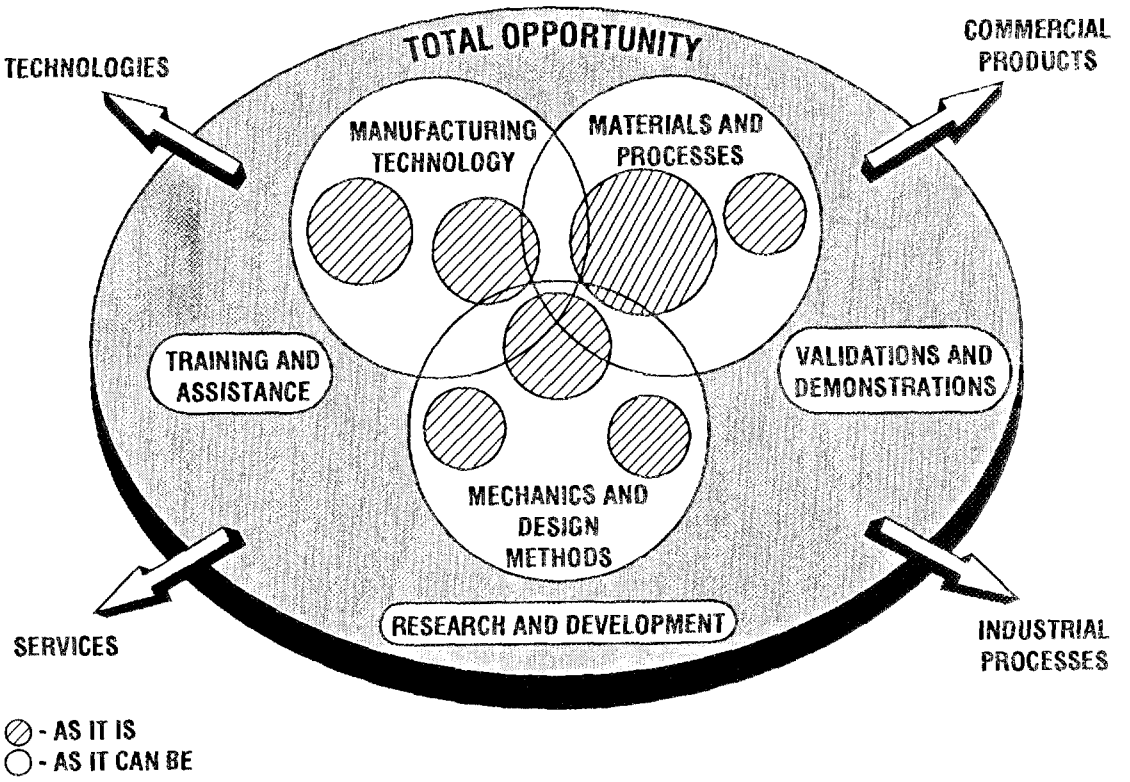

Figure 4.2
Integration of strengths in design, materials, and manufacturing.

The ORNL initiative for Advanced Materials, Design Methods, and Manufacturing Technology will be a integrated, collaborative program that emphasizes (1) precision manufacturing (high quality and benefit in products and processes), (2) agile manufacturing integration (rapid conversion of concepts and technologies into commercial products), (3) environmentally enhanced manufacturing (energy conservation and environmental responsibility), and (4) affordable manufacturing (minimization of total life cycle cost of products and processes). It is part of an Energy Systems–wide initiative that will integrate the strengths of ORNL with other DOE capabilities in Oak Ridge, such as the Centers for Manufacturing Technology at the Y-12 Plant.

This initiative provides a unique opportunity to conduct concurrent, rapid product and process development in partnership with industry, universities, and other Federal agencies. The DOE facilities in Oak Ridge are unique in having both an internationally recognized national laboratory and world-class production facilities. These capabilities span the technology development continuum from basic science to full-scale processing and production. The Oak Ridge complex offers the potential for comprehensive development studies and transition to production in a number of technology areas, such as advanced materials development and processing, environmental management, and manufacturing technology, all of which are of critical importance to the nation.

The long-term interaction of the Oak Ridge complex with industry and academia has resulted in the creation of a manufacturing enterprise that can meet a variety of needs for industry and the nation. Industrial partners have proved that the application of DOE technologies and manufacturing concepts to today's processing problems can enhance productivity, ensure the highest quality at affordable costs, and ameliorate the environmental impacts of manufacturing. Materials, design methods, and manufacturing technologies from DOE facilities have already begun to enhance U.S. industrial competitiveness.

Collaboration across the Oak Ridge complex will be built on a balanced program of (1) R&D, (2) application and demonstration, (3) training and assistance, and (4) technology transfer for commercialization for each element of the initiative. The activities will involve many disciplines and divisions, including the Centers for Manufacturing Technology and the ORNL Metals and Ceramics, Engineering Technology, Instrumentation and Controls, Engineering Physics and Mathematics, Robotics and Process Systems, and Chemical Technology divisions. The initiative will focus on industry-driven programs (market pull) that support the central themes of energy production, use, distribution, and conservation and are environmentally responsible, safe, and of national importance. Strategic relationships and partnerships will be formed with industries and industrial consortia in energy-intensive industrial sectors (e.g., pulp and paper, textiles, chemicals, cements, fabricated metal and ceramic products, and transportation). All programs will have common objectives of enhanced quality and system performance. Concurrent development of cost-effective designs, materials selection, and environmentally responsible manufacturing will help industry to gain a real, sustained competitive advantage in the global marketplace. To provide maximum flexibility and responsiveness to our partners, we will use all available contracting relationships, including user agreements, CRADAs, contracts, and employee exchanges.

The initiative will use existing and planned facilities across the Oak Ridge complex and will be matrix organized to conduct programs. The planned MS&E Complex (described below) and the Centers for Manufacturing Technology will be integral parts of this effort. In addition, as part of ORNL's efforts to upgrade engineering capabilities, a Design Methods and Structural Integrity Center for Advanced Materials will be requested for initiation in 1996. The primary mission of this center will be to develop appropriate design and fracture assessment methodologies for emerging advanced materials, thus accelerating their application and transfer to U.S. industry. The center will address high-temperature materials (ceramics, carbon, intermetallics, and composites) and design methods, fracture mechanics, and structural integrity validation for high-use materials (concrete, metallics, and polymer composites).

In collaboration with other Energy Systems organizations, several manufacturing centers will be established. They will focus on science and processing technology for precision manufacturing.

The programs will develop, validate, and integrate emerging and enabling manufacturing and processing technologies that can be used to produce high-benefit components and systems while achieving the goals of affordability and endurance. Emphasis will be placed on producibility, using an integrated team approach that brings together designers, materials scientists, manufacturing engineers, and end users. The teams will interact closely with the Design Methods and Structural Integrity Center and the MS&E Complex. Design of and with materials must be concurrent with manufacturing and process development to ensure producibility.

Interdisciplinary teams will be established to support the rapid development and transition of innovative technologies to commercial realities. This initiative should make it possible for the U.S. industrial base to be more rapidly invested with DOE technologies.

To effectively transfer manufacturing technologies to small and medium-size companies, rapid response teams will be deployed into the field to address needs on the factory floor. Since use or commercialization of available technologies is the ultimate measure of success, this element of the initiative will be conducted in cooperation with the Regional Outreach Program. The key focus will be affordable technologies and rapid response.

The facilities and personnel for the initiative will come from throughout Energy Systems. Advanced manufacturing modules will be constructed in existing facilities and new facilities requested for initiation in 1996. Table 4.4 lists budget projections for the initiatives.

Table 4.4
Budget projections by fiscal year for the Advanced Materials, Design Methods, and Manufacturing Technology Initiative
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
DOE funding[a]	7.5	18.0	34.0	32.0	40.0	45.0
Non-DOE funding[b]	7.0	15.0	20.0	32.0	40.0	45.0
Total	14.5	33.0	54.0	64.0	80.0	90.0
Operating expense	12.5	30.0	40.0	60.0	76.0	85.0
Capital equipment	2.0	3.0	4.0	4.0	4.0	5.0
Line-item construction	0	0	10.0	0	0	0

[a]DOE programs: DP, EE, ER, and EM.

[b]Non-DOE programs: NASA, Department of Defense, Department of Commerce, Department of Transportation, and industry.

Biotechnology

Biotechnology for the 21st Century is a federal cross-cut initiative, involving 12 federal agencies, that will improve public health, enhance the quality of life, and contribute to economic growth. Developed by the Committee on Life Sciences and Health of the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET), this initiative is designed to maintain the momentum of U.S. leadership in health-directed biotechnology research and to encourage new applications in agriculture, energy, and the environment.

At ORNL, biotechnology research is conducted at various stages of biological organization, ranging from molecular through organismic and system levels, and addresses basic and applied research questions as well as bioprocessing development and appropriate socioeconomic issues. The following discussion covers existing and proposed investigations in all of these areas.

Structural Biology

In its broadest sense, the goal of structural biology is to understand the intricate relationship between biological structure and function. As such, structural biology incorporates experimental techniques that derive three-dimensional structural information from the analysis of radiation in various segments of the electromagnetic spectrum that are scattered by biological materials. Paramount among scattering techniques in structural biology are X-ray and neutron small-angle scattering, crystallography, and several forms of biological imaging. Protein engineering is another important experimental tool in structural biology. Bioprocessing capability and areas of computational biology support the scattering methods. ORNL strengths in all of these areas are combined to address structural biology problems.

As part of the revitalization of structural biology at ORNL, neutron and X-ray small-angle scattering, formerly components of the National Center for Small Angle Scattering Research sponsored by the National Science Foundation, are being recommissioned under FY 1992–FY 1994 Laboratory Directed R&D funds awarded to a team of researchers from the Biology and Solid State divisions. This program will also reactivate a neutron four-circle diffractometer at the HFIR for structural biology research. These activities will enhance structural biology research at these national resource facilities, pending core support from OHER, and will continue an ORNL program as the basis for developing a structural biology program at the ANS. The ANS will permit rapid, precise determination of biological structure by neutron scattering and crystallography; its potential to solve new biological problems will attract structural biologists from all over the world.

Macromolecular X-ray crystallography is being reestablished in the Biology Division. Proteins being studied for three-dimensional structure determination include phosphoribulokinase, human epidermal growth factor (EGF), and mutant analogs designed by ORNL's Protein Engineering Program, as well as human and mouse DNA repair proteins that remove alkylation lesions. Crystallographic studies of nucleosomes reconstituted from a cloned palindrome DNA restriction fragment are funded in part by DOE-OHER.

Mass spectrometry is becoming an increasingly important tool in structural biology; it has broad applications ranging from large biopolymer sequencing to the unambiguous identification and structural characterization of trace biomolecules. The ORNL Analytical Chemistry Division has internationally recognized mass spectrometry expertise and unique capabilities for the characterization of biomolecules. Among these are trapped ion techniques, including Fourier transform ion cyclotron resonance mass spectrometry (FTMS) and quadrupole ion trap mass spectrometry, which have unique capabilities for probing the structure of trapped ions generated from biomolecules. ORNL has led the development of specialized ionization, detection, and structural characterization techniques that can be used with trapped ion mass spectrometers. In addition, a number of other types of mass analyzers and ionization techniques are being employed for the analysis of biomolecules with masses exceeding 100,000 daltons. The ability to image biological materials with mass spectrometry has also been developed in the Analytical Chemistry Division. This tool has wide-ranging applicability for detecting specific molecules in target organs, for example. These capabilities, combined with activities in other divisions that are addressing novel mass spectrometry-based approaches for DNA sequencing, give ORNL a unique position in the application of mass spectrometry to problems in structural biology.

Laser mass spectrometry for DNA segments analysis, which was developed in the ORNL Health Sciences Research Division (HSRD, formerly the Health and Safety Research Division), has proved to be a valuable tool for determination of the structure of DNA and protein. It should play a more important role for structural biology research in the future.

HSRD is working to develop laser-based optical spectroscopies for determining the structural characteristics of biological molecules. These spectroscopies are based on the measurement of chiroptical effects, which provide details about the spatial configurations of the constituent functional groups of chiral molecules. By making these measurements on molecules that have been isolated and

cooled to low temperatures in the gas phase, it will be possible to resolve the structures and the thermodynamic energies of various conformations of the molecules. Such measurements will provide (1) more accurate and precise data for use in computational models of biochemical dynamics and (2) higher resolution input for models of solution-phase chiroptical spectra, increasing the speed and accuracy of conformation analyses in solution.

Biological imaging makes use of expertise concentrated in HSRD and involves a novel class of microscopes that have been identified as a cost-effective, high-volume technique for studying DNA. These microscopes work by scanning a tiny probe very near a surface to which DNA molecules have been applied. The atomic force microscope (AFM) mechanically feels the surface, while the scanning tunneling microscope (STM) electrically feels the sample using a small electric current. A third type of microscope, the photon scanning tunneling microscope (PSTM) invented at ORNL, uses an optical current to a sharpened optical fiber to sense the sample. These instruments constitute new tools for exploring and visualizing biological structure at near-atomic resolution and have the potential for performing genome mapping and sequencing functions. ORNL has a programmatic initiative under the Biological and Environmental Research (KP) Program in the Office of Energy Research in biological imaging and analysis (described in Sect. 5, "Scientific and Technical Programs").

Protein engineering is an active program in the ORNL Biology Division and integrates many activities in molecular genetics. The ability to program specific mutations into cloned genes permits the systematic design of new gene products as mechanistic probes of protein function and the tailoring of operons to alter the regulation of gene expression. X-ray and neutron structural analysis of crystallizable proteins and subsequent molecular modeling with three-dimensional computer graphics will guide the selection of mutant gene products to be constructed and will serve as a tool for predicting the probable structural consequences. Because protein engineering provides an avenue for optimizing functional properties of enzymes, it overlaps with other elements of biotechnology.

Computational biology involves the use of advanced computing devices and techniques for gathering and processing information on biological structures. It includes molecular visualization, rapid processing of macromolecular scattering data, prediction of molecular structure, and simulation of macromolecule behavior after chemical modification or changes in environmental influences. As such, this part of the biotechnology initiative involves a number of ORNL divisions, including Biology, Chemistry, Health Sciences Research, and Engineering Physics and Mathematics. High-performance computing in particular is well suited to studying these types of problems, and the ORNL Center for Computational Sciences will be a valuable resource for the biotechnology initiative.

Cellular Studies

Substantial research in biotechnology at ORNL derives from considerable expertise in cloning recombinant DNA, designing hybridoma cells, studying microbial ecology, and constructing transgenic mice. Cloning, in conjunction with manipulation of cells in vitro, has ushered in the modern era of protein engineering, with applications in medicine, agriculture, waste reduction, and bioprocessing. Monoclonal antibodies, elicited by hybridoma cells, have wide-ranging applications, including the detection of physiological and xenobiotic molecules; they can also be used for the early detection and treatment of cancer. Transgenic mice, constructed by insertional or targeted mutagenesis, provide a means for developing experimental models for human diseases and potentially for mitigating genetic disorders by gene therapy. The modification of plants for better feed and fuel and for the enhanced production of chemicals is another important area (discussed under "Environmental Biotechnology" in this section).

The need for new assays that can provide a basis for better assessments of risks to human health posed by chemical carcinogens is imperative. Rapid advances in the molecular biology of cancer are providing a unique opportunity to design biotechnology-based assays. These biotechnology-based techniques can also be used to design new in vitro assays to assess the

carcinogenic potential of chemical carcinogens and to design new assays for promoters. A newly discovered group of cellular genes, called tumor suppressor genes, are powerful inhibitors of cell growth. Single base-pair mutations or deletions in tumor suppressor genes are now recognized as the most frequent and critical events in tumorigenesis. Further, individuals with these mutations who are at risk for developing cancer can now be identified with biotechnology-based methods before cancer onset. Technologies based on monoclonal antibodies can be used to design new assays for detecting individuals with mutated tumor suppressor genes. Mutations or deletions in individuals at risk can also be detected using assays derived from molecular biology and biotechnology, such as polymerase chain reaction, followed by single-strand conformation polymorphism or heteroduplex formation assays.

Future work will be directed at (1) design of new in vitro assays to test the carcinogenic potential of chemicals associated with energy use and production, (2) design of new assays using antitumor suppressor gene product monoclonal antibodies to directly identify individuals at risk for cancer (leukemia) because of exposure to chemicals, and (3) use of antitumor suppressor gene monoclonal antibodies to evaluate risks to humans exposed to radiation during energy production.

HSRD and the ORNL Biology Division propose a collaborative effort to develop an international information repository to organize and catalog data on the large number of transgenic and mutant animal lines that have been created by investigators worldwide since 1970. This database will facilitate both basic and applied research by (1) establishing a central information source on transgenic and targeted mutation technology; (2) encouraging technology transfer and commercial utilization of transgenic animals; and (3) making possible the linkage of homologous gene and chromosome segment data across specific lines. The information included in this database will be obtained directly from researchers and from the scientific literature. To ensure the technical integrity of the database, all entries will be reviewed by the corresponding investigator(s) or by ORNL research staff. Discussions will be initiated with the Informatics Group at the Johns Hopkins University School of Medicine to explore the feasibility of a cooperative arrangement to make this database available to the public via Internet and to link it with other appropriate databases.

Analysis Techniques

Changes in DNA are the most fundamental of the effects of mutagens and carcinogens. Several approaches to detect such changes are components of the ORNL biotechnology program. The classical DNA labels, radioisotopes and fluorescence, are being supplemented with stable isotopes to provide new, rapid avenues to detecting alteration in DNA by resonance ionization spectroscopy. New approaches in mass spectrometry may replace current gel electrophoresis methods to detect DNA changes very rapidly. Characterization of a single DNA molecule is becoming feasible as a result of recent improvements in scanning probe microscopy methods, in which the probe measures electron tunneling or atomic force on the DNA surface. Also at the molecular level, a DNA matrix that is being developed will use the basic hybridization specificity of one DNA to another to detect sequence changes that lead to mutations and cancer.

Advances in biotechnology have often been accelerated by developments in microscopy. ORNL has been actively pursuing novel scanning probe techniques, including atomic force microscopy, electron scanning tunneling microscopy, and photon scanning tunneling microscopy. These promise very high resolution coupled with the unique ability to operate in physiological solutions to image the dynamics of biochemical reactions and living systems. Sample preparation techniques have been developed to rapidly and reliably image biomolecules such as DNA. Currently, protein-DNA and protein-protein interactions are being studied to help understand the microscopic form-function relationships and to perform rapid high-resolution mapping. Hybrid instrument techniques combining optical and force probes are being developed to follow the dynamics of the receptors on living membranes. Soft X-ray spectroscopy and soft X-ray photon tunneling microscopy, both using synchrotron radiation, offer new methods of biomolecular imaging and analysis that

should yield data crucial to biotechnology. This work is fully cross-disciplinary and involves the expertise of physicists, chemists, and biologists.

Laser-induced surface-enhanced Raman techniques are used to provide vibrational and structural information on DNA, nucleotides, and proteins. Biological markers are valuable tools for investigating recovery of ecological systems following restoration and for evaluating exposure potential to released components. Development of useful biological markers involves interdisciplinary research spanning areas from molecular biology to analytical techniques. The application of biological markers to human exposures or disease states requires the development of novel, ultrasensitive analytical techniques. DNA adducts in fish and mammals have been used to determine exposure of organisms to polyaromatic hydrocarbons. Elevated levels of mixed-function oxidase have been used to evaluate direct toxic effects, and the return of sensitive species to habitat has provided direct evidence of the success of restoration activities.

New structural techniques are being devised for use with FTMS to characterize biopolymers, such as DNA, which have been modified as the result of exposure to chemicals or radiation. Because biological activity is strongly dependent on the specific isomeric structure of a DNA adduct, it is important to have capabilities that can establish the identity of the adduct unambiguously, locate its site of attachment to a nucleotide, and determine the position of the modified nucleotide in an oligonucleotide. Ions generated by matrix-assisted laser desorption (MALD) ionization may be structurally probed using a variety of gas phase reactions developed for use with FTMS. The advantage of this approach is that it can be used to obtain detailed structural information from modified biomolecules at the low-picomole level without the need for authentic standards. As these techniques have been developed, they have been applied to a number of collaborative studies with biologists from ORNL and around the world.

Advanced instrumentation based on ion trap mass spectrometers is being developed for the rapid detection of trace organics in a variety of biological and environmental matrices; thus, it has significant potential for biotechnology applications. This approach minimizes the need for sample preparation and eliminates the need for on-line chromatographic separations. As a result, analyses may be completed in as little as 3 min with these new techniques, compared to many minutes or even hours with conventional analytical methods. For example, low part-per-billion (ppb) levels of certain drugs may be detected in as little as 10 μL of urine or cow's milk, with a total analysis time of less than 3 min. Detection limits for all 34 volatile organic compounds on the EPA Target Compound List at levels of 5 ppb or lower in water have been demonstrated with this technique as well. Numerous other biotechnology applications for this type of instrumentation are possible, including process monitoring, dosimetry, and drug screening. Efforts are also being made to enhance instrument operation and to reduce both the size and power requirements of the instrumentation in order to simplify use of the instrument in the field by nonexpert operators.

Bioprocessing

Bioprocessing research and development at ORNL addresses advanced processing concepts and systems that can be used for energy production and conservation, conversion of renewable feedstocks to fuels and chemicals, processing of fossil fuels, treatment of hazardous or radioactive wastes, and solving other national problems. In general, bioprocessing approaches operate at much milder operating conditions than conventional technology, and they are environmentally benign. Bioprocessing R&D at ORNL is expanding, with current support from DOE, other government agencies, and the industrial sector. Future prospects exist in resource recovery, cleanup of contaminated soil and groundwater, alternative processing in the chemical industry, and the Space Exploration initiative. Industry involvement is growing, with several developed technologies transferred to the commercial sector.

Recent advances include the use of chemically modified enzymes to enhance the conversion of coal to liquids, new techniques for the conversion of renewable feed materials to commodity

chemicals, advanced bioreactor concepts that enhance productivity by a factor of four or more, and use of bioadsorbents for the cleanup of wastewater. Cooperative research efforts being developed with industry include advanced bioreactors for the chemical industry, bioremoval of uranium from mine wastes, bioconversion of coal, and removal of sulfur from petroleum by advanced bioprocessing techniques.

The Bioprocessing Research and Development Center (BRDC) at ORNL was established in 1991 to maintain good coordination of programs in this area, encourage multidisciplinary interactions, and serve as a vehicle for further program expansion. Efforts within the BRDC are organized into applied biological research in support of bioprocessing development, bioengineering research, and bioprocess development. The BRDC organizes workshops and meetings, including the annual international symposium series, "Biotechnology for Fuels and Chemicals," now in its 15th year. The Bioprocessing Research Facility is also maintained for industrial and academic use, especially in cooperative and proprietary research.

ORNL is one of four national laboratories participating in a consortium on bioprocessing R&D under a memorandum of understanding; the others are Argonne National Laboratory, Idaho National Engineering Laboratory, and the National Renewable Energy Laboratory. Within this consortium, ORNL has the primary responsibility for advanced bioprocessing concepts.

Environmental Biotechnology

Environmental biotechnology includes research in biomonitoring, biological markers, ecotoxicology, environmental chemistry, plant genetics, and microbial ecology. Efforts range from the subcellular level to the ecosystem and are directed at understanding how chemicals cause responses in biological systems and how biological systems enhance degradation and/or immobilization of contaminants in soils and groundwater. Environmental biotechnology research provides opportunities for application to environmental restoration and bioremediation and the genetic engineering of high plants for use as producers of alternative fuels or other valuable chemicals. Currently the principal focus is on environmental restoration at the Oak Ridge sites, although use of biological markers and bioremediation strategies at other sites, both nationally and internationally, is being pursued.

Environmental biotechnology work focuses on the transfer of existing capabilities in biomonitoring, biomarkers, and ecotoxicology to other sites (with particular emphasis on transfer of the underlying scientific principles); linkage of these three areas and their use in risk assessment and long-term monitoring; strengthening and expanding expertise in microbiology and genetics to allow us to be the premier DOE organization for understanding, and hence modifying, microbial activity in the subsurface; and demonstration of our capabilities in modifying and controlling genetic activities in higher plants. In each of these areas we anticipate increased involvement with universities and the private sector, joint ventures, and other approaches that will enable us to make major technical advances.

Applied biological research is carried out in support of bioprocessing concepts with an emphasis on photobiology, enzymology, and microbiology. Engineering research stresses advanced bioreactor concepts, enhanced biocatalyst systems, separation technology for product recovery and purification, and system monitoring and control. Several of the resulting advanced bioprocessing concepts have progressed to commercial applications.

Development of technology for site remediation is also an important component of this research area. Efforts have included development of sensing devices based on fiber optics for detection of bacterial metabolism associated with degradation of wastes and monoclonal antibodies immobilized on optical fibers to provide remote sensing of hazardous chemicals in groundwater and in subsurface soil samples. Related studies use the bacteria found in association with free-living amoebae in the degradation of toxic wastes. These unique amoebae/bacterial consortia have demonstrated the ability to degrade or alter trichloroethylene and a variety of explosives. Field tests of

the efficacy of these microorganisms will be undertaken in technology transfer initiatives with private industry.

The modification of plants for the enhanced production and isolation of valuable compounds is an important research initiative, coupling plant physiology with molecular biology. Enhanced production of cellulose in biomass feedstocks is a model system, where genetic transformation techniques are being applied to amplify endogenous indoleacetic acid concentrations in hybrid poplars, altering primary carbon metabolism to increase cellulose deposition. Such studies are providing a greater understanding of basic plant metabolism that is being used to elucidate biochemical mechanisms of tolerance to environmental stress. For example, accumulation of solutes, which confer water stress tolerance in hybrid poplar, is being evaluated as a molecular/subcellular indicator of stress tolerance in plant tissue culture systems. Future research into natural plant products may yield novel bioactive compounds that can be mass produced in bioreactors containing plant cell suspension culture, using protocols derived from the model system.

Another effort in biotechnology combines those components of fundamental research which are related to the responses of environmental species with applied microbiology, engineering capabilities, and chemical detection and sensing to address environmental restoration and waste management issues. Collaborative efforts with other national laboratories and universities and cooperative efforts with private industry through CRADAs are major strategies in this program.

Social Issues

Ultimately, successful application requires acceptance of biotechnology by the public. Simulation models are being used to evaluate the transport and survival of genetically engineered microorganisms in the environment; in addition, the ethical, legal, and social implications of genome manipulation are growing concerns that are central to the human and environmental risk analyses being conducted.

Budget

Budget projections for the Biotechnology Initiative are given in Table 4.5. Funding is provided by a number of sources, including the Office of Energy Research, the Assistant Secretary for Energy Efficiency and Renewable Energy, and other DOE and non-DOE offices and programs.

Table 4.5
Budget projections by fiscal year for the Biotechnology Initiative
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Operating expense	21.7	23.1	25.1	26.3	27.6	29.0
Capital equipment	0.8	1.4	1.5	1.5	1.2	1.2

Environmental, Life, and Social Sciences Complex

The development of the Environmental, Life, and Social Sciences (ELSS) complex has been a vision of the Laboratory for many years. The expansion of the West End Development Area of

ORNL is of extreme importance to accommodate the growing programs in the environmental, life, and social sciences and will also support DOE's increasing emphasis on ES&H activities. The ELSS Complex will provide new high-technology laboratories for the expanding R&D needs of the Biology, Health Sciences Research, Environmental Sciences, and Energy divisions of the Laboratory and will offer modern facilities in place of old buildings, many of which are crowded, inefficient, and in need of repair. New facilities consist of three proposed line items—the CBS (described earlier in this section), the Earth Systems Facility, and the Biological Imaging and Photonics Laboratory—and several general plant project (GPP) upgrades and other miscellaneous facilities.

All of these facilities will be located near existing structures occupied by the Environmental Sciences Division (ESD), as shown in Fig. 4.3. This will enhance collaborative interactions within the ELSS directorate. Programmatic emphases in the directorate will include structural biology, protein engineering, biotechnology, the human genome, global environmental studies, risk management, environmental restoration, social sciences, energy technologies for developing countries, the energy and environmental aspects of transportation systems, and energy efficiency. Table 4.6 provides funding projections for the ELSS Complex. Funding is sought from a variety of sources, including the Office of Energy Research.

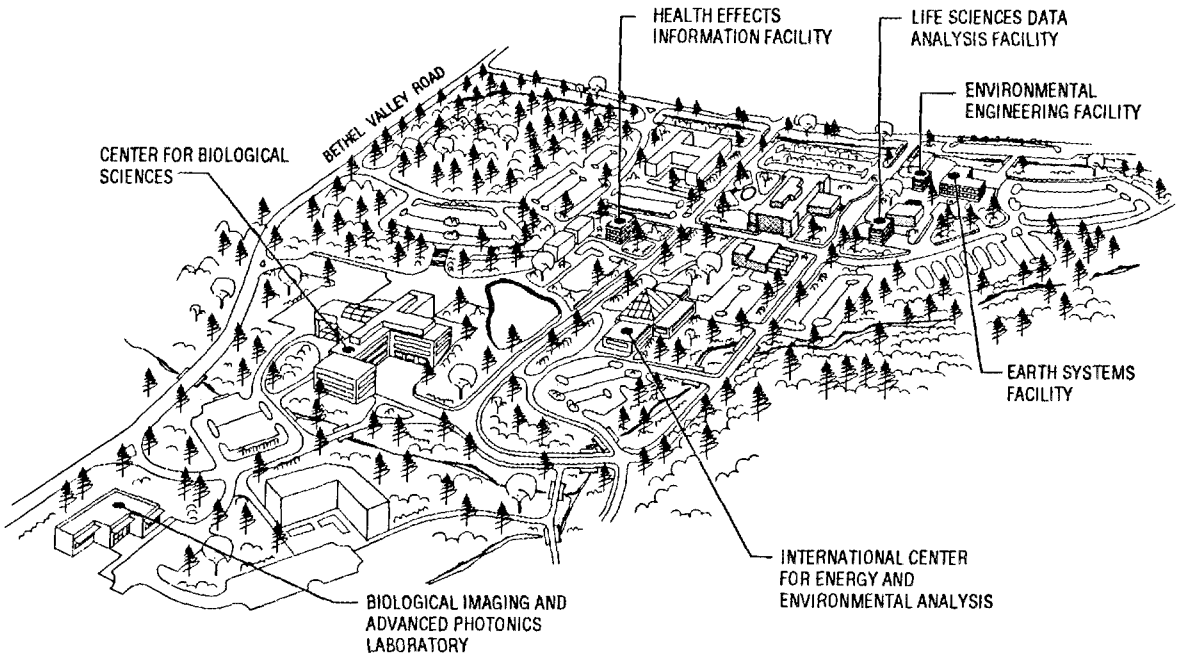

Figure 4.3

Conceptual plan for the ORNL Environmental, Life, and Social Sciences Complex, to be located in the West End Development Area.

Earth Systems Facility

The Earth Systems Facility will support major OHER/ESD initiatives in global change, subsurface science, and ecological research. (See Sect. 5, "Scientific and Technical Programs," for descriptions of programmatic initiatives in these areas.) These initiatives incorporate a diversity of specific projects, including the Atmospheric Radiation Measurement (ARM) program, the Carbon Dioxide Information Analysis Center (CDIAC), carbon cycle modeling, colloid transport, environmental biotechnology, spatial heterogeneity, the Walker Branch Watershed, theoretical ecology, and the National Environmental Research Park. Multidisciplinary approaches involving

Table 4.6
Budget projections[a] by fiscal year for the development of the Environmental, Life, and Social Sciences Complex
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Program KP						
Center for Biological Sciences[b]	0.4/0	0.1/16	0.1/42	0/40.7		
Biological Imaging and Advanced Photonics Laboratory				0/1.5	0/6.5	
Earth Systems Facility	0.3/0	0.3/0	0.4/0	1.5/2	0/10	0/7.6
Program EW/AT (General Plant Projects)[c]						
Environmental Biotechnology Laboratory Expansion			0/1.1			
West roads and parking improvements		0/1.1				
Other construction						
International Center for Energy and Environmental Analysis[d]	0/0.78	0/1.02	0/0.72	0/0.72	0/0.48	
Steam system upgrade, west end[e]	0/2.7					

[a]Operating expense/capital costs.

[b]The budget projection for the Center for Biological Sciences assumes that construction starts during FY 1995.

[c]Not listed are the Life Sciences Data Analysis Facility, approved in FY 1990; the Health Effects Information Facility, approved in FY 1992; and the Environmental Engineering Facility, approved in FY 1993. Each of these facilities has a cost of $1.1 million.

[d]This facility is proposed as an expense-funded, leased modular building.

[e]Program KG, capital costs only.

biogeochemical cycling, model development and evaluation, hydrology, climatology, geographic information systems and mapping, and data management draw on field-oriented, laboratory, computational, and theory staff. The Earth Systems Facility will be dedicated to better integration of empirical research, modeling, and data systems activities, which is an essential step for the success of these new initiatives. The facility will be a two-story structure with approximately 50,000 ft^2. The total cost of the Earth Systems Facility is estimated at $19 million. Programmatic funding is being sought from a variety of sources, including OHER.

This facility will meet two principal needs. The first is for a facility that can accommodate the unique physical requirements imposed by computational research. The structure of existing facilities does not support the networking capabilities needed for successful modeling and data management integration activities. In addition, laboratories designed for computational research are lacking, and power supplies are inadequate for computing tasks.

The second need is for integrated measurement, modeling, and theoretical research. The groups supporting the Global Change, Subsurface Science, and Ecological Research initiatives of OHER/ESD are now dispersed among six buildings. It is essential for modelers, researchers conducting experiments and making field measurements, and data systems staff to have space for laboratories, offices, and computational facilities in reasonable physical proximity. Adequate, convenient work space will facilitate the iterative process of models leading to measurements and to improvement of the databases needed to address the complex issues embedded in the OHER/ESD major initiatives at ORNL. Consolidation of ORNL staff in this new facility will enhance communication, stimulate new ideas, and improve research efficiency.

Biological Imaging and Advanced Photonics Laboratory

The Biological Imaging and Advanced Photonics Laboratory will serve as a focal point for integrating diverse activities in biological imaging and advanced photonics, such as those associated with the programmatic initiatives on advanced environmental photonics and the Biological Imaging and Analysis Center (see Sect. 5, "Scientific and Technical Programs"). The Biological Imaging and Advanced Photonics Laboratory would also support the Biological and Environmental Research Program initiative of the ORNL Genome Program and the structural biology component of the Laboratory-wide initiative on biotechnology (discussed earlier in this section), in which technologies based on neutrons and mass spectrometry are integrated with biological imaging. In photonics, breakthroughs in areas such as advanced laser and fiber-optic spectroscopy are increasingly critical for applications in characterizing and monitoring during energy production, in defense operations, and in DOE's accelerated programs for environmental restoration and waste management and biological research. Biological imaging is tied to the use of electron STMs, AFMs, and PSTMs for providing images of biological samples. Future research will include development of methodologies for a broad range of biological samples, development of hybrid instruments for chemical mapping, and the use of combined infrared and optical spectroscopy for chemical mapping of biological samples using the PSTM. Collocating the scientific staff and research equipment for these two initiatives will lead to synergisms in the areas of photonic and biological imaging, with ultimate benefits to research in a number of key areas for DOE, including the human genome and biotechnology.

The Biological Imaging and Advanced Photonics Laboratory will consist of laboratories and offices with total floor space of about 12,000 ft^2 and a total cost of about $8 million. Programmatic funding is being sought from a variety of sources, including OHER.

General Plant Projects

The GPPs for the ELSS Complex consist of the Life Sciences Data Analysis Facility, the Health Effects Information Facility, and the Environmental Engineering Facility, all of which have been approved (as noted in Table 4.6). Expansion of existing space in ESD is being considered to augment ORNL's resources for biotechnology research.

In general, the facilities will consist of office space, laboratories, computer rooms, and conference rooms. A multitude of programs and funding sources will be served by these facilities.

Other Construction

The International Center for Energy and Environmental Analysis will house Energy Division staff who work on social science issues, the energy and environmental aspects of transportation systems, energy efficiency, and environmental impact statements. These staff members are currently spread out among a number of buildings at ORNL; consolidating them into a new facility will promote collaboration in these research areas.

Work done in this facility will support the Laboratory's initiatives on Transportation Technologies and Systems and on Energy and Environmental R&D for a Sustainable Future (described in this section), as well as the Center for Risk Management (described in Sect. 5, "Scientific and Technical Programs").

The facility is proposed as an expense-funded, leased modular building, with total floor space of about 35,000 ft^2. This includes office space, room for minicomputers, and meeting space. Supplementing these facilities will be a lodge and conference center and other ancillary support structures that will enhance collaboration with the scientific community outside ORNL and help to promote interactions with universities, industry, and other laboratories in areas related to environmental, life, and social sciences.

Materials Science and Engineering Complex

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

Among DOE's national laboratories, ORNL has one of the strongest materials programs. Indeed, the ORNL programs in high-temperature metals and alloys, ceramics, composites, and superconductors are unparalleled successes. ORNL has established programs in synthesis and processing science that span a wide range of materials systems. ORNL is also a leader in user programs and technology transfer through CRADAs and licensing. These activities have grown rapidly and will increase even faster because of recent legislation removing barriers to technology transfer.

Universities and colleges in the southeastern United States have numerous innovative materials R&D programs that collectively span a broad range of disciplines, from materials chemistry to materials physics to materials engineering and testing. During the last few years, the Southeastern Universities Research Association (SURA) and the Oak Ridge Institute for Science and Education (ORISE) have explored ways to simplify and encourage joint materials research activities with ORNL. This approach not only benefits large, established programs but also enhances small programs at individual universities through synergistic interactions. In addition, the University of Tennessee at Knoxville (UTK) and ORNL have a close working relationship. Faculty and graduate students from UTK participate in collaborative research at ORNL, and ORNL staff members serve as adjunct professors and thesis advisors at UTK.

To make the ORNL materials facilities and those of the industries and universities in the region available for joint cooperative projects, ORNL proposes the Materials Science and Engineering (MS&E) Complex. By consolidating a number of existing programs and providing new buildings and facilities, the MS&E Complex will enhance collaborative interactions in materials science and engineering. The plan of the complex addresses identified national, regional, and local needs for materials R&D, and it will support ORNL's rapidly expanding user programs and technology transfer activities.

The MS&E Complex also meets a critical need to alleviate poor conditions in materials facilities at ORNL. The need to replace substandard laboratories in the Solid State Division has been recognized for decades, and during this time the condition of these facilities has deteriorated. The added space will also alleviate severely overcrowded conditions in the Metals and Ceramics Division.

The complex will be constructed in the late 1990s to the east of the present ORNL site, as shown in Fig. 4.4. It will include a Center for Study of Advanced Materials (CSAM), a Solid State Research and Processing Science Center, a Center for Advanced Microstructural Analysis (CAMA), aand Composite Materials Laboratory. A new facility for the Office of Guest and User Interactions (OGUI) is also part of this initiative.

The CSAM is an initiative of the university community of the Southeast, led by SURA. This center will encourage joint materials research activities with ORNL by establishing a university/industry presence at the MS&E Complex. The Solid State Research and Processing Science Center will satisfy the need for modern solid-state laboratories at substantially lower cost

*National Research Council, *Materials Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials*, National Academy Press, Washington, D.C., 1989.

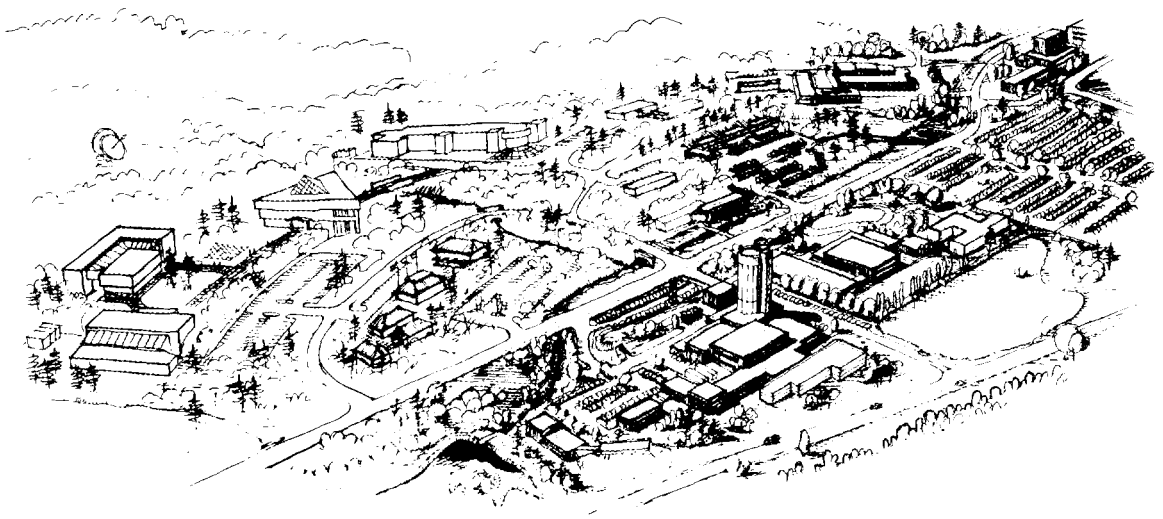

Figure 4.4
Materials Science and Engineering Complex.

than refurbishing existing structures to meet present standards imposed by ES&H regulations and the Occupational Safety and Health Administration (OSHA). The CAMA is a response to the need for building that can house the next generation of instrumentation with vibration-sensitive optics. A new building will house such instrumentation and bring together under one roof a full range of modern microanalytical instrumentation.

To ensure marketplace success, industry must guide and participate in the R&D and manufacturing science activities. Active participation of industry will be fostered by the MS&E Complex, which will make available ORNL's wide-ranging multidisciplinary skills; capabilities in fabrication, characterization, and testing; independent and objective outlook; and ability to work with and protect proprietary information.

Center for Study of Advanced Materials

The CSAM responds to a proposal for the establishment of a campus-like presence at ORNL in the form of a center for materials science and engineering, with the object of increasing the materials impact of SURA member universities.

The goal of the CSAM is to develop broadly based scientific initiatives in materials science and engineering that will reflect the special talents, facilities, and capabilities residing in the Southeast. These initiatives will address nationally significant problems that are of interest to both DOE and the university participants and that transcend the capabilities of individual institutions. The center is intended to integrate and enhance the entire spectrum of materials science and engineering opportunities at ORNL and to make them accessible to the southeastern universities.

The CSAM will support the ongoing research and graduate education programs of the southeastern universities by providing a site at ORNL for students and faculty to perform joint research, by increasing access to ORNL user facilities and staff, by holding workshops, and by otherwise promoting enhanced interaction among university, industry, and national laboratory researchers. The SURA communications network, SURAnet, would be tied into the CSAM to provide

scientific interchange through broadcasts of seminars, lecture series, workshops, and other significant technical presentations or discussions.

The CSAM would be operated through the cooperation of SURA, ORISE, and ORNL. Support for the CSAM is envisioned as joint funding from DOE's Office of Basic Energy Sciences, the National Science Foundation (NSF) Division of Materials Research, state funds from participating universities, and industry partnerships. Establishment of the CSAM would involve construction of a building next to ORNL at an approximate cost of $17 million; operating costs are projected at $4 million to $5 million per year. Budget projections are listed in Table 4.7.

Table 4.7
Budget projections for the planning period by fiscal year for the Center for Study of Advanced Materials
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Operating expense	0.0	0.0	0.0	2.0	3.0	4.0
Capital equipment	2.0	0.5	0.5	0.5	0.5	0.5
Line-item construction	0	0	0	1.0	8.0	7.5

Solid State Research and Processing Science Center

The Solid State Research and Processing Science Center will allow the consolidation of research activities that are now located in 15 separate buildings into a central facility as part of the MS&E Complex. The 80,000-ft^2 building will provide about 100 offices and 40 laboratories for state-of-the-art materials R&D. The new facility will replace aging facilities that cannot be upgraded to accommodate modern research or to comply with ES&H standards at acceptable costs, and it will enhance the effectiveness of the solid-state research program as part of the highly interactive MS&E Complex. Table 4.8 provides budget projections.

Table 4.8
Budget projections for the planning period by fiscal year for the Solid State Research and Processing Science Center
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Line-item construction	2	1	0	0	0	0

Center for Advanced Microstructural Analysis

As microanalytical instrumentation becomes more sensitive, performance is limited not by the instruments themselves but by the environment in which they are situated. Electromagnetic fields, building vibrations, and even low acoustic noise act to degrade performance. When most existing facilities were designed as general-purpose laboratories, little attention was paid to the environmental issues that now restrict performance. The CAMA will be a national resource for the user community, providing a state-of-the-art site for location of the broad range of microanalytical instrumentation available at ORNL, including analytical and high-resolution electron microscopes, atom probes and

field-ion microscopes, surface analysis instrumentation, X-ray diffraction facilities, and mechanical property microprobes.

Building services and traffic patterns in the CAMA facility will be routed to enhance the isolation of the most sensitive instruments, and provisions will be made for remote operation of many of these instruments. The design of the 52,000-ft^2 building will emphasize information management and allow for acquisition and processing of digital images. Integrated facilities such as these, which contain a concentration of state-of-the-art equipment and are available to a broad spectrum of outside users, will become essential to future research as the need grows and the equipment becomes more complicated and expensive. The cost of the CAMA is currently estimated at $42.2 million. Design will start at the beginning of FY 1998; construction will be completed in FY 2000. Budget projections are given in Table 4.9.

Table 4.9
Budget projections for the planning period by fiscal year for the Center for Advanced Microstructural Analysis
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Capital equipment	0.5	1	2	1.5	1.0	*a*
Line-item construction	0	0	0	0	5.0	14.0

[a]To be determined.

Composite Materials Laboratory

The Composite Materials Laboratory will build on ORNL work on polymer, carbon-carbon, and metal and ceramic matrix composites that is found in several different organizations. The principal ORNL divisions involved in composites are the Engineering Technology Division and the Metals and Ceramics Division. Other divisions of Martin Marietta Energy Systems, Inc., with supportive specialties such as nondestructive evaluation (NDE) and materials characterization, are expected to participate, and UTK will contribute as well. The Center of Excellence for Materials Processing is the focal point for composites research at UTK. University departments involved in composites research include Materials Science; Engineering Science and Mechanics; Mechanical, Aerospace, and Chemical Engineering; Chemistry; and Physics.

Composites R&D involves several technology areas: materials science and processing, mechanics, prototypic fabrication and evaluation (including NDE), manufacturing development and testing, and technology transfer. The focus of materials science and processing is on creating engineering materials with appropriate properties for applications by controlling composition, molecular structure and microstructure, and process variables. ORNL and UTK have a unique R&D capability for analyzing the mechanical behavior of composite structures through a predictive failure theory based on concepts of fracture mechanics and basic thermodynamic principles, environmental effects, and ORNL's extensive applied mechanics capabilities with attendant large-scale computing support. This collective capability can relate microstructural properties to structural performance. Critical to the use of composites is the ability to detect and to measure the size of defects by NDE—an area in which ORNL's experience in the examination of composites using ultrasonics and penetrating radiation (primarily X rays) will be invaluable. State-of-the-art X-ray computer tomography equipment and a digital image analyzer for radiographs have significantly enhanced ORNL's capabilities to evaluate composite materials.

The Composite Materials Laboratory is planned as a 50,000-ft^2 building that will house an interdisciplinary team of more that 100 ORNL and university scientists, engineers, students, and supporting staff. Table 4.10 lists budget projections.

Table 4.10
Budget projections for the planning period by fiscal year for the Composite Materials Laboratory
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Capital equipment	0.2	0.5	1.0	0.4	0.5	*a*
Line-item construction	0	0	0	0	5.0	15.0

[a]To be determined.

Office of Guest and User Interactions

The OGUI is ORNL's interface with a large community of guests and users. The OGUI facilitates guest and user access to collaborative research facilities at ORNL by disseminating information about designated user facilities; identifying user facilities and other opportunities for collaborative research; providing assistance with the access and approval procedures that visits to ORNL require; negotiating legal agreements on research interactions; and assisting visitors with housing, transportation, and other support. The OGUI is also responsible for coordinating all CRADA agreements initiated at ORNL.

The OGUI supports 10 ORNL user facilities that are important components of the Laboratory's mission (see Sect. 7, "Technology Transfer and Science and Mathematics Education"). These user facilities satisfy national R&D needs, broaden the ORNL research base, and leverage the available funding.

The OGUI handled more than 4000 visits in 1992 by scientists and engineers from universities, industries, and other federal laboratories. This number is expected to increase as partnerships attain even more importance in the Laboratory's mission. The construction of a new building for the OGUI is proposed as a general plant project (GPP) for FY 1993.

Oak Ridge as a National Fusion Nuclear Site

The national fusion program is aimed at the development of fusion as an energy source. The National Energy Strategy, incorporating fusion as an energy program, has set the goal of a fusion demonstration reactor by about the year 2025. Much of the development needed to achieve this goal relates to fusion nuclear technologies, yet the U.S. fusion program has no nuclear-capable site at which to conduct the necessary research.

The existing major tokamaks are coming to the end of their planned experimental programs. Two of these tokamaks, the Joint European Tokamak (JET) and the Tokamak Fusion Test Reactor (TFTR), will demonstrate substantial levels of nuclear fusion power (tens of megawatts) for short pulses (seconds). Indeed, JET has already produced about 1.7 MW of power in a preliminary experiment. Thus, the nuclear technology development phase of fusion is upon us.

Many of the major facilities planned for the future require a nuclear-capable site. These include the next large tokamak, the International Thermonuclear Experimental Reactor (ITER), which is being planned as an international collaboration; a 14-MeV neutron source for fusion materials development; and the proposed small devices needed for fusion nuclear technology development. None of the existing U.S. fusion facility sites can accommodate these facilities. Our potential international partners—particularly the Europeans—have identified suitable sites. For example, the French moved the bulk of their fusion effort from Fontenay-aux-Roses and Grenoble to Cadarache some years ago and now have a fusion infrastructure on a nuclear-qualified site suitable for ITER and other fusion nuclear facilities.

We recommend that DOE hold a competition to identify a suitable fusion development site, at which any major future capital investments would be made. This would give the United States a competitive position for ITER and for other facilities that might be proposed for international collaboration, such as the 14-MeV neutron source. This initiative could be coupled with a proposal for operation and management of the site in a way that would involve more programmatic involvement by the private sector.

We propose that, in such a competition, a portion of the Oak Ridge reservation be considered as the prime U.S. location for the nuclear facilities needed for development of the magnetic fusion energy program. The Oak Ridge reservation offers a number of sites that could serve this purpose.

Oak Ridge is an ideal location for such a site because of the availability of an existing scientific and engineering infrastructure in fusion, materials, and nuclear processing, coupled with the availability of the required electrical power, cooling capability, and environmental characteristics. Furthermore, the communities in the Oak Ridge area have shown strong support for such initiatives in the past.

Transportation Technologies and Systems

The transportation sector offers a number of opportunities to the research community. Transportation consumes two-thirds of the oil used by the United States; thus, any significant reduction in U.S. dependence on imported oil will require improvements in this area. In addition, transportation affects the nation's health. Air quality in most large urban areas is below minimum health standards, largely because of automobile and truck emissions.

Transportation is also a vital component of U.S. industry. The domestic automobile industry is the largest segment of manufacturing, accounting for one out of every seven jobs in America. The industry is on an uneven playing field, with global competitors producing out of newer plants, using newer equipment, and enjoying government R&D support. Regaining the lead in automotive production will require a new era of teamwork in this country between government and industry.

Investments in transportation infrastructure have not kept pace with the nation's need for mobility, economy, and safety. While our system is still the best in the world, congestion now threatens this mobility. The Federal Highway Administration estimates that delays from congestion alone result in losses of $100 million annually. The Intermodal Surface Transportation Efficiency Act of 1991 signals a much-needed and wide-ranging attack on these problems with its goal of developing an economical, environmentally sound, and energy-efficient transportation system. The Energy Policy Act of 1992 adds a large number of transportation-related provisions. Some of the more significant are provisions to accelerate the use of alternative fuels and electric vehicles, to establish tax credits for clean vehicles, and to require DOE to carry out additional transportation R&D.

This ORNL initiative is contained in a broader initiative, the Oak Ridge Transportation Technology Center (ORTRAN), which is being undertaken by Martin Marietta Energy Systems and includes transportation programs at DOE's Y-12 Plant and K-25 Site. The ORNL goal is to secure a

major share of the DOE resources that are identified for collaboration with industry on automotive programs. Since some transportation research responsibility lies outside the DOE charter, we will seek to broaden our activities by expanding our participation in Department of Transportation (DOT) and Department of Defense (DOD) programs. We intend to work in close collaboration with Y-12 and K-25 in areas such as hybrid vehicle technology, materials, emissions reduction, advanced manufacturing processes, and transport of hazardous materials.

ORNL is in a strong position to undertake important research assignments on transportation. We have widely recognized strengths in many vital disciplines. Our materials capabilities are among the best in the country. We have managed the Ceramic Technology Project for the DOE Office of Transportation Technologies since 1983. We have worked with the automotive industry on applications of intermetallics. We have a background in fabricating high-strength polymer composites, derived from the uranium enrichment program. The High Temperature Materials Laboratory (HTML) serves as a unique facility for joint laboratory-industry materials research. We have worked with the automotive industry on topics of fuel composition, combustion, and catalysis related to alternative fuels since 1984 and have conducted fleet evaluations of both electric and methanol fuel vehicles. We are working with the Motor Vehicle Manufacturers Association on refrigerants that do not contain chlorofluorocarbons (CFCs) for mobile air conditioners.

In our Center for Transportation Analysis, we have provided analytical support to the DOE Office of Transportation Technologies and the Office of Policy, Planning, and Analysis for the past 15 years. We perform analyses of motor vehicle fuel economy, sales, and technology and assist with program planning. Results are published in the annual *Transportation Energy Data Book*. This work has expanded into support of the DOT's national highway and intermodal planning activities and support of the national defense transportation missions of the DOD. For example, ORNL is recognized by both agencies as the only authoritative source of national transportation network databases.

ORNL provides analytical and technology development support to several DOE offices and programs that have transportation operations responsibilities. Innovative techniques for providing improvements in areas such as regulatory compliance have been developed through the creation of expert systems and the automation of traditionally manual functions. Development of hazardous materials packaging, including design and testing, has been carried out for DOE and industry to meet complex certification requirements. As a provider of broad-based capabilities in transportation systems development, ORNL supports both overall mission accomplishment and highly specialized technical components.

Our technology transfer program has been widely noted and emulated. We have moved aggressively to license our R&D results for application by industry. We were among the first to use the CRADA mechanism to work with industry, and we have shown that we can respond to industry's needs by establishing CRADAs in just a few weeks' time to meet requirements for rapid action.

We will seek to expand our program in the following areas. In each of these elements there is strong industrial or public sector interest matched with important ORNL capabilities.

- **Automotive manufacturing.** ORNL and Y-12 have complementary capabilities in cost-effective precision machining, hydroforming, design and fabrication, application of high-performance computing, and process certification. Several automotive industry CRADAs are already under way, with DOE funding from Defense Programs (DOE-DP) and Energy Efficiency and Renewable Energy (DOE-EE). Others are projected, pending availability of sufficient funds.
- **Hybrid/clean vehicle.** There is a rapidly increasing realization that future requirements will demand vehicles with performance characteristics very different from those now on the highways. Emissions will have to be close to zero, energy efficiency must be dramatically increased, and recycle of materials at the end of the vehicle life must be facilitated. All of these changes must be accomplished in a cost-effective manner. The new vehicle will most likely have a hybrid electric propulsion system with an ultralightweight body. ORNL participation could include development of propulsion systems, permanent magnet motor-generators, power electronics, flywheels, and

advanced magnetic materials. Lightweight materials technology developed in other ORNL programs includes polymer composites, high-strength low-alloy steels, aluminum and magnesium alloys, and metal-matrix components. ORNL is already working on emissions reduction with CRADAs on sensors and catalyst materials, particularly for NO_X reduction. Battery performance is still an elusive target, and one or more ORNL concepts will be investigated.

- **Intelligent vehicle highway systems.** Advanced computing, communication, and control technologies are needed to cope with energy-wasting traffic congestion. Continuing and prospective ORNL research includes work on crash-avoidance systems, measurement of vehicle energy efficiency and emissions, vehicle guidance and control, vehicle and driver diagnostics, traffic control simulation, advanced traffic control centers, human factors in system design, fast computing and application-specific integrated circuits, dynamic route planning, and system evaluation methodologies. ORNL is leading efforts to develop a regional coalition to conduct and evaluate operational tests of advanced vehicle highway technologies, which could lead to operation of a national user facility centered on the high concentration of interstate highway traffic passing through East Tennessee.

The following additional areas of transportation systems research make use of ORNL capabilities and are expected to be of interest to DOE, DOT, DOD, and other government agencies.

- **Infrastructure modernization.** This task would apply ORNL expertise in structural engineering, materials science, and sensor design to the problems of premature deterioration of pavements and bridges.
- **Military transportation.** ORNL has made important contributions to military transportation planning during the Persian Gulf crisis and the Somalia relief effort. The nation's new defense posture requires much additional research to meet the needs of a rapidly evolving situation.
- **Hazardous materials.** ORNL experience in packaging and transporting hazardous materials can be applied to a wide range of problems. Increasingly, state and local governments find themselves in need of technical assistance in this area.
- **Transportation planning and analysis.** All of these research areas require continuing analysis and assessment to integrate the R&D with policy actions and to redefine research priorities to meet changing requirements.

Baseline projections for the initiative are indicated in Table 4.11. The projections include continuation of existing ORNL transportation programs (about $50.1 million in FY 1993) but do not include the industry portions of joint projects or the portions of the projects that will be done by the Oak Ridge Y-12 Plant or the Oak Ridge K-25 Site.

Table 4.11
Budget projections by fiscal year for the Transportation Technologies and Systems Initiative
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
DOE funding[a]	47.2	55.3	67.8	63.0	68.2	72.4
Non-DOE funding[b]	13.4	15.4	18.1	21.5	25.0	28.9
Total	60.6	70.7	75.9	84.5	93.2	101.3
Operating expense	57.1	66.7	71.9	80.5	89.2	97.3
Capital equipment	3.5	4.0	4.0	4.0	4.0	4.0

[a]DOE programs EE, DP, EM, RW, EH, ER, and PE.
[b]Non-DOE: DOT and DOD.

Center for Environmental Technology

The Center for Environmental Technology (CET) has been established to integrate related activities within the Oak Ridge Complex, to provide a focus on market-driven technology programs, and to accelerate the commercialization of environmental innovation. ORNL, the Environmental Restoration and Waste Management Programs organization based at the Oak Ridge K-25 Site, and the Oak Ridge Y-12 Plant are partners in this endeavor, which embraces a new approach to eliminating barriers to developing and testing environmental technologies.

The CET will link technology users and suppliers from the private sector, DOE, and other government agencies to deploy cost-effective, innovative, safe, and economically viable technologies that will decrease the cost of environmental restoration and waste management. The CET will accelerate the development, demonstration, and commercialization of improved technologies by providing a framework of services, facilities, and demonstration sites that expedites regulatory contracting and related operations.

CET users can draw on the specialized resources of the Oak Ridge Complex; these resources include scientists, engineers, technicians, and regulatory experts as well as world-class laboratories and unique user facilities for full-scale demonstrations. The CET places special emphasis on establishing cooperative arrangements with federal and state regulators to gain regulatory support and contracting procedures to expedite on-site demonstrations and technology transfer. The long-term goal of the CET is to assist the U.S. environmental industry in regaining global competitiveness, coupled with increased U.S. employment.

The CET's mission is to

- deliver proven and accepted environmental remediation and waste management technologies to the market at an accelerated rate;
- provide user-friendly facilities that actively support private sector involvement on site;
- make environmental remediation and waste management projects at the Oak Ridge Complex a national showcase for technologies by serving regional needs while drawing on national resources;
- provide environmental products, services, and management expertise to federal, state, and local agencies; and
- educate, train, and retrain personnel to ensure the availability of an environmental work force by the year 2000.

The success of the CET will depend on its effectiveness in interacting with critical stakeholders, including regulators, industry, government agencies, and the public; these groups will be intimately involved in the continued implementation and evolution of the CET to effectively expedite the acceptance of innovative technologies and the commercialization process.

The CET's strategic approach to achieving its mission is to invest in technologies that are strongly coupled to the industrial market, leading to a significant return on DOE's investment, and to leverage this investment with other agencies and industry. By accelerating the technology maturation process within a focused program, the CET will reduce the cost of the environmental remediation and waste management mission by significantly more than the cost of the initial investment. Achieving cost effectiveness requires (1) application of the most capable technology development talents to meeting the identified environmental remediation and waste management needs, which are also driven by the environmental marketplace, and (2) identification of the most cost-effective technologies, which will meet not only the technological needs but also the sociological, economic, political, and regulatory demands imposed.

The CET was dedicated on May 14, 1993. Efforts during the remainder of FY 1993 will be devoted to development of the business plan, staffing of key functions, and evaluation and selection of potential demonstrations. A major planned activity is the establishment of a Memorandum of

Cooperation with one or more commercial partners, such as the Oak Ridge Waste Management Association, before the end of FY 1993. Budget projections for the CET are given in Table 4.12.

Table 4.12
Budget projections by fiscal year for the Center for Environmental Technology
($ in millions)

	1993	1994	1995	1996	1997	1998
Operating expense	1.5	9.5	11.0	12.5	13.0	13.5

Energy and Environmental R&D for a Sustainable Future

ORNL proposes a major initiative to develop and implement energy and environmental technologies that will enable the world to meet its energy needs in the 21st century in ways that will be economically, environmentally, and institutionally sustainable.

The heart of this effort is the challenge of providing energy services for development in such emerging areas as Asia, Latin America, and Eastern Europe. In 1992, DOE adopted a new mission to "promote the wise selection of energy technologies and improved operating and maintenance practices—on both the energy supply and demand sides—in order to address both development and environmental objectives in the energy sectors in developing countries and in countries with their economies in transition." Reasons for selecting this mission included contributing to the management of global environmental change, improving the ability of the U.S. private sector to compete in international markets for energy technologies and services in an era of concern about environmental change, and contributing to U.S. national security by reducing the risk of political and economic instability in developing areas.

Many observers believe, in fact, that ensuring a smooth transition from nonsustainable energy systems (based largely on fossil fuels) to sustainable systems for meeting ever-larger global energy needs is the greatest single challenge facing the energy R&D enterprise in the next several decades. This challenge is rooted in innovative technology R&D, because current energy technologies are inadequate to meet economic and institutional requirements in many countries, especially looking several decades into the future. However, it is more than a matter of technology R&D alone. It involves complex relationships among technology, economics, and environment, and it puts a premium on effective technology cooperation and transfer as well as technology development. This kind of complex, multidisciplinary mission is where the DOE national laboratories are at their best.

Since the early 1970s, ORNL has been preparing to help meet this challenge. For example, ORNL has developed a decade-long base of experience with energy and environmental projects in more than 30 developing countries (largely supported by non-DOE sponsors); it has established a Center for Global Environmental Studies; and it recently joined with the University of Tennessee at Knoxville and the Tennessee Valley Authority to create a Joint Institute for Energy and Environment (JIEE), strongly oriented toward global issues.

Meanwhile, DOE and other federal agencies share a rapidly growing interest in energy and environmental R&D for global markets and needs. In 1992, DOE established a program for Assisting the Deployment of Energy Practices and Technologies (ADEPT) and began preparing a set of export assistance strategies. The Energy Policy Act of 1992 directed the creation of a multiagency

Committee on Energy Efficiency Commerce and Trade (COEECT) as a partner of the well-established Committee on Renewable Energy Commerce and Trade (CORECT). The federal government has committed itself to a sizable U.S.–Asia Environmental Partnership.

Building on its experience, its knowledge of the issues, and the growing interest of DOE and other federal agencies, ORNL intends to pursue R&D initiatives in three principal areas:

- Energy efficiency improvement. The Laboratory will emphasize technology R&D in refrigeration and other heating, ventilation, and air conditioning (HVAC) technology areas; decision support tools such as Integrated Resource Planning (IRP); transmission and distribution system improvements; and transportation efficiency improvement. In line with the commitments of COEECT and other DOE programs, these efforts will stress relationships with the U.S. private sector.
- Environmental management. ORNL will seek to apply its expertise in environmental impact assessment, environmental technology R&D and technology transfer, environmental restoration, and facility management in developing countries and in supporting U.S. and international development assistance agencies. A particular interest will be assisting JIEE in developing a major center for energy and environmental training for developing country counterparts.
- Biomass energy development. ORNL expects to be a leader in accelerating the use of biomass as a fuel source for modern energy systems in developing countries, emphasizing biomass for electric generation, thermal energy, and mechanical energy (complementary to the lead role of the National Renewable Energy Laboratory in liquid fuel conversion technologies). Again working with the U.S. private sector, ORNL will build on its important current roles in DOE R&D programs in woody and herbaceous biomass production to develop an integrated approach to biomass energy utilization, sensitive to such issues as environmental management and the seasonality of biomass production.

Other areas of Laboratory interest include institution-building, especially collaboration with sister R&D institutions in developing countries; chlorofluorocarbon (CFC) emission reduction; and potential applications of other nonfossil energy supply technologies, ranging from hydropower to nuclear energy.

Budget projections for this initiative are indicated in Table 4.13. Funding for activities in this area is already being provided by DOE's Offices of Environmental Protection, Energy Efficiency and Renewable Energy, and Environmental Restoration and Waste Management and by several offices of the U.S. Agency for International Development (AID).

Table 4.13
Budget projections by fiscal year for the Energy and Environmental R&D for a Sustainable Future Initiative

	1994	1995	1996	1997	1998	1999
Operating expense	4.3	8.0	9.8	11.0	11.8	12.5
Capital equipment	0.2	0.5	0.7	1.0	1.2	1.5
Total[a]	4.5	8.5	10.5	12.0	13.0	14.0

[a]Roughly one-quarter of the funding is expected to be from non-DOE sponsors in early years, declining to 10–15% in out-years.

Other Initiatives

The following initiatives are proposed under program discussions in Sect. 5, "Scientific and Technical Programs."

- Office of Energy Research
  - High-Energy Physics Research Program and the ORNL Detector Center
  - Radioactive Ion Beams/Recoil Mass Spectrometer
  - Development of Melton Valley as a Strategic Resource for Nuclear and Radiochemical Technology
  - Center for Excellence in Research Reactors
  - Retention of the Pool Critical Assembly
  - Computational Biosciences
  - Advanced Photonics for Environmental Needs
  - Biological Imaging and Analysis Center
  - Subsurface Science Research
  - ORNL Genome Program
  - Center for Global Environmental Studies
  - Educational Technology
- Office of Nuclear Energy
  - Center for Excellence in Research Reactors (see Office of Energy Research)
  - Retention of the Pool Critical Assembly (see Office of Energy Research)
  - Actinide Recycle
- Assistant Secretary for Environment, Safety, and Health
  - Center for Risk Management
  - Health Physics Instrumentation Center of Excellence

5 • Scientific and Technical Programs

U.S. Department of Energy

Office of Energy Research

The Office of Energy Research (DOE-ER) is the largest single sponsor of research at ORNL. It supports ORNL's major research programs in fusion energy, the basic physical sciences, and biological and environmental sciences. Funding levels for DOE-ER programs are listed in Table 5.1.

Table 5.1
Office of Energy Research major program summary by fiscal year
($ in millions—BA)[a]

Budget and reporting code	Major program	1992	1993	1994	1995
AT	Magnetic Fusion	30.2	33.4	35.5	37.8
KA	High-Energy Physics	0.4	0.4	1.0	0.9
KB	Nuclear Physics	15.7	12.1	15.2	15.4
KC	Basic Energy Sciences	113.1	112.3	155.4	273.6
KD	Energy Research Analyses	2.6	1.9	2.2	2.6
KG	Multiprogram Energy Laboratory Facility Support	5.6	5.8	16.2	21.4
KP	Biological and Environmental Research	29.9	31.4	30.5	47.6
KS	Superconducting Super Collider	0.2	0.0	0.5	0.6
KT	University and Science Education	0.6	0.1	0.0	0.0
KU	Laboratory Technology Transfer	2.1	2.0	4.7	3.8
KV	University and Science Education, Defense-Related	1.1	1.4	1.7	2.3
	Landlord activities[b]	(3.9)	2.2	23.1	23.4
Total		197.6	203.1	286.0	429.4
Percentage of total Laboratory funding		33.7	31.0	36.9	42.9

[a]Operating BA, capital equipment, construction, and proposed construction as noted in Table 11.5.
[b]Includes general-purpose equipment and general plant project funding and several field work proposals for the Occupational Safety and Health Administration (OSHA) and other safety activities.

Magnetic Fusion—AT

The Fusion Energy Program at ORNL is a major component of DOE's Magnetic Fusion Program, the plans for which are outlined in the National Energy Strategy (NES). Two characteristics distinguish ORNL in this activity: (1) the extensive collaboration, both nationally (with numerous universities, industries, and national laboratories) and internationally (with ten countries), and (2) the breadth of the component subprograms in physics, technology, and systems studies. Work is carried out primarily in the ORNL Fusion Energy Division, with major contributions by several ORNL divisions, by the Engineering and Computing and Telecommunications Services (C&TS) organizations of Martin Marietta Energy Systems, Inc., and by the Oak Ridge Y-12 Plant.

The goal of the national magnetic fusion program, as stated in the NES, is to prove that fusion energy is a technically and economically credible energy source by having an operating demonstration plant by 2025. Achieving this goal will require increasing emphasis on the nuclear aspect of fusion. ORNL is a key participant in the program because of its multidisciplinary energy programs, the breadth of its fusion program, its capability for integration of fusion research and development (R&D) areas, its excellent record in technology transfer to industry, and the potential of the Oak Ridge reservation as a site for fusion nuclear technology R&D facilities, including major deuterium- and tritium-burning experiments. In support of the NES, ORNL's objective is to have a leading role in

- the integration of confinement and technology issues needed for understanding fusion physics and for improving the toroidal confinement concept,
- the solution of physics and technology issues for the operation of a toroidal reactor at high duty factor or steady state,
- the attainment of adequate system reliability and maintainability,
- the development of radiation-resistant and low-activation materials,
- the development of a nuclear-capable site for fusion technology R&D, and
- the broader exploitation of technologies and capabilities developed in the fusion energy program and the transfer of these technologies to American industry.

Support for the ORNL program comes from three subprograms in the Office of Fusion Energy (DOE-OFE): Applied Plasma Physics (AT05), which funds theory, atomic physics, diagnostic development, and small innovative experiments; Confinement Systems (AT10), which funds confinement experiments, such as the Advanced Toroidal Facility (ATF) and the Tokamak Physics Experiment (TPX), and some applications of plasma technology; and Development and Technology (AT15), which supports materials research, plasma technology, the International Thermonuclear Experimental Reactor (ITER) project, and systems studies. Support for applications outside fusion comes from a variety of sources both within and outside DOE.

Theory • The ORNL fusion theory program uses theoretical and computational methods to formulate, validate, and apply models of plasma behavior in toroidal confinement systems. Successful models lead to improvements in the operation of present systems and in the design of future systems. A primary emphasis is on understanding plasma confinement and its limitations in tokamaks; similar emphasis is given to an alternative toroidal confinement concept—the stellarator/torsatron.

Efforts are directed toward applications that improve the U.S. tokamak initiatives (the international ITER effort, the national TPX effort, and the Advanced Reactor Innovation and Evaluation Study) and that enhance the U.S. and world programs in the stellarator field. Research focuses on the following areas:

- Development of plasma simulation models and computational approaches, and application of models to specific experiments so that the models can be validated and improved. ORNL participates in the Numerical Tokamak Project (NTP), a Grand Challenge in computational science that is being addressed by a consortium of six national laboratories and five universities. The NTP is developing numerical models for studying the behavior of high-temperature plasmas confined in a tokamak geometry. Computational work is carried out at the National Energy

Research Supercomputer Center of Lawrence Livermore National Laboratory, the Advanced Computing Laboratory of Los Alamos National Laboratory (LANL), and the ORNL Center for Computational Sciences.

- Analysis of the anomalous transport of particles and energy, as driven by instabilities and modified by nonplasma effects such as ionization/recombination processes at the periphery. Instability-driven turbulent processes are assessed using simulation models. ORNL has an active role in the national Transport Task Force, which applies theory and experiment to gain a better understanding of transport phenomena in toroidal devices.
- Development of models for instabilities driven by alpha particles, in preparation for the deuterium-tritium (D-T) phase of operations in the Tokamak Fusion Test Reactor (TFTR) at Princeton Plasma Physics Laboratory (PPPL).
- Definition, development, and modeling of fueling and heating techniques to adjust profiles, control energy and particle sources, and modify loss factors. Areas of application include edge physics and divertor performance, helium removal, and pellet fueling.
- Development of large-scale computational models of radio-frequency (rf) heating and noninductive current drive. These models are used to understand the results of high-power heating experiments; to guide the design of rf current drive experiments; and to establish the design basis for future heating and steady-state current drive systems.
- Development of computational tools and techniques for the analysis and design of rf antennas.

Atomic Physics • The experimental atomic physics program, which uses a state-of-the-art electron cyclotron resonance (ECR) source to study atomic collisions relevant to fusion processes and plasma diagnostics, and the closely coordinated atomic theory program have made major progress in measurement of benchmark systems for testing theoretical approximations; in deduction of trends from studies of isoelectronic, isonuclear, and isoionic sequences; and in finding new parameterizations for maximizing the predictive power of theory. This progress is expected to continue.

The Controlled Fusion Atomic Data Center provides bibliographic and evaluated numerical data on atomic and molecular processes that are relevant to fusion R&D. A bibliographic database is updated through journal searches by a network of expert consultants, and recommended numerical data are available in book form and in an internationally accepted electronic format, ALADDIN, through cooperation with the International Atomic Energy Agency (IAEA). Both of these databases will soon be made widely available through Internet access to a host workstation at ORNL. During the planning period, heavy emphasis will be placed on obtaining, analyzing, and publishing the atomic data needed to support edge physics, divertor modeling, and shield and limiter requirements for ITER and TPX.

In the diagnostics development program, a promising laser-based diagnostic for fusion alpha particles, successfully tested on ATF, will undergo further testing on the Alcator C-Mod tokamak at the Massachusetts Institute of Technology (MIT). The development of requirements for application of the method to ITER will be completed.

Spherical Tokamak Program • The Spherical Tokamak (ST) Program develops the physics base for low-aspect-ratio tokamaks, tests improvements, quantifies potential applications of the ST to tests of critical fusion technologies (e.g., steady-state divertors and fusion blankets), and clarifies viable future reactor concepts. This research is organized with the following integrated activities:

- Collaboration with institutions active in ST experiments and device design at modest plasma currents. Experiments in this collaboration include the Small Tight-Aspect-Ratio Tokamak (START) and its upgrade at Culham Laboratory, United Kingdom, and GLOBUS-M at the Ioffe Institute, Russian Federation, which is being designed under an "enhanced" collaboration agreement.

- Initiatives to use existing fusion research facilities for testing ST physics, and possibly for testing steady-state divertors, at low cost. New initiatives include the possible use of facilities at PPPL and Culham Laboratory.
- Preliminary studies to clarify viable ST embodiments of a steady-state D-T volumetric neutron source driven to full noninductive current and a gain factor $Q \geq 1$. Such a device would be well matched to the expertise, facilities, and sites available in Oak Ridge.
- Development of small, fully maintainable ST reactor concepts that have low capital costs and are characterized by plasmas with beta on the order of unity, self-generated currents, a strongly diffused edge, and disruption-free operation.

Advanced Toroidal Facility • The main focus of the Confinement Systems subprogram at ORNL has been the ATF experiment, the world's largest stellarator. ATF was designed to demonstrate steady-state, disruption-free operation at high beta (the ratio of the plasma pressure to the pressure of the confining magnetic field), leading to a reactor-relevant configuration, and has the flexibility to study various magnetic configurations and make unique contributions to the understanding of toroidal confinement. The ATF program goals for FY 1994 through FY 1997 are

- demonstration of $\langle\beta\rangle > 4\%$ (if theoretically predicted instabilities do not prove experimentally limiting), low collisionality, and improved confinement for pulse lengths up to 30 s;
- optimization of the stellarator configuration and operational techniques for improvement of the performance of the Japanese Large Helical Device (LHD) stellarator and for the design of a better D-T stellarator; and
- development of steady-state power and particle handling.

ATF is the only device with the necessary combination of configuration flexibility, beta capability, pulse length, access for power and particle handling, and ion cyclotron range of frequencies (ICRF) heating capability to accomplish these goals.

This program represents a cost-effective approach because ATF and most of its heating systems already exist. It is timely because ATF can provide data four years before LHD and thus contribute to the next generation of reactor development. A window of opportunity exists in 1994–1998, during which ATF can make crucial contributions to the development of the stellarator concept and allow the United States to capitalize on the international program at relatively low cost.

Stellarator development follows two major routes: (1) sheared systems, such as ATF and the Heliotron-E and Compact Helical System stellarators in Japan, leading to LHD, and (2) low-shear systems, such as the German Wendelstein VII-AS, leading to Wendelstein VII-X. Each type of system has important reactor-relevant features, such as the possibility of $\langle\beta\rangle \approx 5\%$ (if predicted instabilities do not interfere), dependence on magnetic field modularity, and a natural divertor. The best system for development of a stellarator-based reactor must be determined from experiments. ATF was designed to complement other stellarators in the world program by testing the principles of magnetohydrodynamic (MHD) optimization and the effects of the magnetic configuration on low-collisionality transport.

The ATF program features collaborations with researchers from other institutions in the United States, Japan, Spain, Russia, Ukraine, and Germany. Key contributions to understanding have been made in a number of areas, including Mercier stability, scaling of the plasma-driven (bootstrap) current, plasma edge turbulence and associated transport, effects of magnetic field perturbations and electric fields, and global transport scaling. Encouraging results for the scaling of the global energy confinement time indicate that the factor of ≥ 1.5 improvement in confinement time needed for an attractive fusion reactor may be attainable.

ATF has been shut down since November 1991 for replacement of two damaged segments in one of the two large helical windings that produce the main confining magnetic field. Repairs are scheduled to be finished in FY 1993, and ATF should be ready for restart by the end of FY 1994.

Edge Physics, Particle Control, and Plasma Technology • ORNL has an expanding role in the integration of physics and technology for edge physics, particle control, plasma fueling,

and rf heating. The systematic development of capabilities in these areas supports the development and operation of facilities such as ITER and TPX. In the near term, efforts are concentrated in a number of collaborative programs, both national [TFTR, the Princeton Beta Experiment–Modified (PBX-M), DIII-D, Alcator C-Mod, LANL] and international (JET, TEXTOR, Tore Supra, and ENEA/Frascati). These programs focus on techniques for understanding and controlling the plasma boundary, pellet fueling, and ICRF heating and current drive. In the longer term, ORNL has important roles in the ongoing design and R&D for TPX and ITER. Technology development is supported by the AT15 program; experimental applications are generally supported by the AT10 program; the theoretical underpinnings are funded through the AT05 program.

Edge Physics and Particle Control • The long-term goal of the edge physics and particle control program at ORNL is to develop particle control scenarios for steady-state plasma operation that are relevant to the next generation of tokamak experiments (ITER and TPX). These scenarios cover dynamic control of wall effects, pellet/beam/gas fueling, and controlled exhaust of both fuel and helium ash. The ORNL program is addressing these issues on existing tokamaks (DIII-D, Tore Supra, and TEXTOR) to develop models that can be used in specifying particle control schemes for future devices.

ORNL has a lead role in helium transport and exhaust studies on both DIII-D and TEXTOR. Helium ash removal is a major R&D issue for ITER, and these programs are providing both new data and modeling to improve the helium pumping schemes for future tokamaks. An extensive program of edge physics measurements is in progress on DIII-D, Tore Supra, and TEXTOR with the dual objective of supplying a database for ITER and supporting the validation and application of modeling codes. On TPX, ORNL has the physics responsibility for pumping and gas handling and the lead design role in vacuum pumping.

RF Technology and Experimental Applications Program • ORNL is responsible for the technology development, design, and application of rf power on major fusion experiments, whose systems will provide the development basis for ITER and TPX systems. The long-range goal of the RF Technology Program is to develop systems that are cost-effective and compatible with operation in fusion power reactors. The technologies are usually prototyped on the Radio Frequency Test Facility (RFTF) or other ORNL facilities to eliminate defects and to test or validate codes at minimum cost. Extensive collaborations play an important role in the development of critical areas such as ICRF current drive, phase control, long-pulse technology and physics, advanced launchers, and advanced heating scenarios. Plans include activities in

- ICRF current drive antenna array and phase control systems. The results of initial fast wave current drive experiments on DIII-D, conducted with an ORNL antenna array, are being used in designing a new 8-MW array to be installed in FY 1994. We have tested the second-generation phase control system for the new array. This work has led to a collaboration with the Joint JET Undertaking in which ORNL will be responsible for the design of a 32-MW system for JET and will also develop the real-time matching needed for longer pulse or steady-state machines such as ITER and TPX.
- Long-pulse technology and physics issues. Both the technology of antenna components that can survive long-pulse operation in the plasma environment and the physics base to characterize the plasma response must be developed. Again, collaborations further the state of the art. An ORNL antenna has delivered 54 MJ in 27 s to the Tore Supra plasma; work is under way to improve the Faraday shield configuration and material so that >120 MJ can be achieved. We are designing a third-generation Faraday shield to handle this elevated performance. The development of this technology is especially important to TPX, since it has a long-pulse/steady-state mission. The Tore Supra collaboration is also being used to measure how rf power modifies the edge plasma and affects antenna component lifetimes and plasma confinement. Other collaborations supporting this effort involve experiments on TFTR and DIII-D.
- Advanced launcher development and advanced heating scenarios. Waveguide antennas have substantially better power capability and mechanical ruggedness than conventional loop antennas.

Using these attributes to full advantage on large (or high-field) machines such as TPX requires innovations such as the folded waveguide (FWG) launcher and a way of removing the linkage between frequency and ion resonance. After extensive testing of an FWG on RFTF in the megawatt range, we have begun a collaboration with MIT on the high-field Alcator C-Mod device to validate the performance of the FWG concept in FY 1995. On the basis of RFTF tests, we expect that the injected power density can be extended to >20 $MW \cdot m^{-2}$ (thereby reducing the required port size). We are exploiting collaborations on TFTR and DIII-D to develop direct electron heating techniques, which would remove the frequency link to ion resonances. All of these collaborations support the development of advanced heating concepts and the extension of ICRF heating and current drive to other regimes.

Pellet Injector Technology and Plasma Fueling Applications Program • ORNL is recognized as the international fusion community's leading laboratory in developing and applying advanced plasma fueling systems for magnetic fusion. The fueling group is integrated with plasma theory, modeling, particle control, confinement, rf, and edge physics efforts at ORNL and at other fusion laboratories through extensive national and international collaborations (DIII-D, TFTR, JET, Tore Supra, LANL, and ENEA/Frascati). The long-range goal of this program is to develop ultralong-pulse to steady-state pellet injection systems for D-T operation at moderate (≤1-km/s) and high (≥3-km/s) velocities. Applications on experiments are undertaken to demonstrate injector and fueling capabilities. Since no single experiment requires the full range of capabilities, applications are divided among a number of facilities (e.g., tritium at the LANL Tritium Systems Test Assembly, TFTR, and JET; long pulses at Tore Supra). In addition, the program provides specialized injector systems and expertise to support experimental programs. During the next five years, the ORNL program will concentrate on the following technology and physics areas, with particular emphasis on long-pulse particle control issues:

- Develop long-pulse to steady-state, reliable pellet fueling systems for TPX and ITER.
- Develop high-speed (3- to 5-km/s) pellet fueling technology for TPX and ITER to provide innovative approaches for improved plasma operating regimes. A key element of this program is the recently approved collaboration with ENEA/Frascati to develop a repetitive two-stage light gas gun.
- Develop safe and reliable tritium pellet fueling technology for ITER.
- Support the successful completion of the TFTR D-T phase with the ORNL tritium-compatible, high-speed pellet injector. The experimental program will focus on ITER-relevant plasma conditions.
- Install a versatile repeating pneumatic injector on DIII-D as part of an integrated collaboration on pellet-enhanced confinement in rf-heated plasmas, particle control, and edge physics.
- Upgrade the existing Tore Supra centrifuge injector for longer pulses (up to 2-min operation) to study particle control and transport in long-pulse plasmas in which a pumped divertor is used for active particle control.
- Define, develop, and implement a tritium fueling capability for the next D-T phase on JET. After completion of the TFTR D-T program in late 1994, JET will provide the only opportunity to explore physics issues relevant to D-T operations. A new collaboration will build on past collaborations with PPPL and JET in this area.

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

Materials Program • The Fusion Energy Materials Program focuses on the development of reactor structural materials, ceramics, and first wall and high-heat-flux materials. Within DOE-OFE, these efforts are supported by the neutron-interactive materials and the plasma-interactive materials programs. The ORNL effort supports U.S. participation in ITER, as well as the ultimate objective of making fusion an economically competitive and environmentally attractive energy source.

Structural Materials • In the structural materials program, the primary emphasis remains on the qualification of austenitic stainless steels for ITER and the development of low-activation ferritic steels, vanadium alloys, and structural ceramic composites (e.g., SiC/SiC) for a demonstration reactor and future fusion power reactors.

Austenitic stainless steels are the leading candidate for structural materials in ITER because of their advanced state of development and commercial application. In a collaborative program with the Japan Atomic Energy Research Institute, we are investigating the effects of fusion reactor damage levels on the engineering properties of these alloys. Central to this effort is the irradiation of these alloys in the High Flux Isotope Reactor (HFIR) with tailoring of the neutron spectrum to produce damage levels (transmutation-produced helium and displacements per atom) equivalent to those that will be produced in a fusion reactor. These experiments provide data and understanding of radiation response at the temperatures and damage levels required for ITER.

Development of low- or reduced-activation materials is critical to achieving fusion's potential as a safe and environmentally attractive energy source. Development of low-activation ferritic steels focuses on the most critical or limiting property of this class of alloys: the radiation-induced shift in ductile-to-brittle transition temperature and the resulting reduction in fracture toughness. Our research on vanadium alloys focuses on their chemical compatibility with proposed fusion coolants and the effects of radiation on their fracture toughness.

The effects of irradiation on the dielectric properties of ceramic insulators are of critical importance in the design and operation of numerous fusion reactor systems (e.g., rf heating and plasma diagnostics). We are carrying out in situ measurements of the loss tangent during ionizing radiation and ionizing plus displacive radiation and exploring the recently discovered phenomenon of radiation-induced electrical degradation (RIED), a rapid, permanent decrease in conductivity following an incubation period. Changes in the loss tangent will affect the choice of materials and the design of heating systems for ITER. RIED could have very serious implications for the selection of materials and the design of systems requiring ceramic electrical insulators.

First Wall and High-Heat-Flux Materials • Research on graphite and carbon-carbon composites is part of the plasma-interactive and high-heat-flux materials programs. These materials must exhibit extremely high resistance to thermal shock, erosion, and neutron damage. Optimum thermal shock resistance is assumed to be offered by appropriately designed carbon-carbon composites (i.e., selected fibers, matrices, and architectures). Current work is directed toward the optimization of these materials for neutron damage resistance.

Advanced Systems Program • The Advanced Systems Program focuses on the definition and conceptual design of future tokamak projects. The conceptual design efforts on TPX and ITER provide the basis for planning on both a national and an international scale. Both of these initiatives are broadly supported by the ORNL Fusion Program. Specific design aspects are discussed here. The Advanced Systems Program is also exploring facilities for testing fusion reactor technologies and materials.

TPX • ORNL has established a partnership with PPPL for the design and construction of TPX. The conceptual design effort is complete, and plans are under way to begin the capital project in 1994. A senior scientist from ORNL, on assignment at PPPL, serves as the Deputy Project Manager, and a department manager from the Energy Systems Engineering organization is one of three engineering managers for the project.

In the physics area, ORNL has a lead role in rf systems, edge physics, and particle control and carries out supporting work in modeling and analysis of fueling, magnetics, and plasma transport. In technology, ORNL's primary areas of responsibility are rf systems, fueling, remote handling, and vacuum pumping.

ORNL is primarily providing the engineering design for the rf heating and current drive system, with physics direction from PPPL and MIT. The steady-state fueling system will require significant development of new concepts for pellet forming and feed systems. The remote handling system relies heavily on technology development within the ORNL Robotics and Process Systems

Division; ORNL is also responsible for integrating the maintenance requirements, applying the Laboratory's expertise in engineering design and development of remote handling facilities. The requirements for and the design of the vacuum pumping system will be closely connected to the edge physics and particle handling activity. Responsibility for design and fabrication will ultimately be subcontracted to industry, as will much of the total TPX design and fabrication. In several developing areas (e.g., rf and remote handling), industrial partners will be involved early for the purposes of technology transfer.

ITER • ORNL provides the ITER program with expertise in design engineering, physics, plasma technology, fusion materials, and systems analysis. A senior ORNL scientist and a senior engineer are responsible for managing the overall U.S. ITER Home Team activities. Several ORNL scientists and engineers serve as U.S. ITER Task Area Leaders, coordinating and managing work in plasma performance, rf systems, containment structures, remote handling, structural materials, and design integration. In addition to the Home Team activities, several ORNL employees will serve as members of the Joint Central Team, working at one of the three co-centers in Garching, Germany; Naka, Japan; and San Diego, California.

ORNL is carrying out a number of ITER-related design (physics and engineering) and R&D tasks. In accordance with DOE guidelines on increasing industrial participation, ORNL has awarded industrial contracts in two technology development areas. In remote handling R&D, the industry team is led by Rockwell International Corporation's Rocketdyne Division (Canoga Park, California); supporting team members are General Atomics (San Diego, California) and CIMCORP Precision Systems, Inc. (Shoreview, Minnesota). The team for vacuum vessel R&D will be led by Pitt–Des Moines, Inc. (Pittsburgh, Pennsylvania), with Grumman (Bethpage, New York) as a supporting team member.

In physics design support, ORNL areas of responsibility are plasma performance (including confinement, operational scenarios, and transport modeling) and operational limits (MHD stability, density limits, etc.), and coordination of associated physics R&D within the U.S. base program. In engineering design and technology R&D, primary areas of responsibility include containment structures, remote handling, structural materials, pellet fueling, and rf systems.

Work in containment structures is directed toward key vacuum vessel issues with the goal of establishing a cost-effective approach for design and fabrication. In remote handling, the primary areas include remote cutting and welding, standard component and process development, and tooling. Both areas provide opportunities for utilization of U.S. industrial capabilities and do not require excessive facility investments. In structural materials, the primary emphases are qualification of austenitic stainless steel, evaluation of radiation effects on components, and development of vanadium alloys and structural ceramic composites. Proposed ORNL work in pellet fueling includes injector and extruder development and hardware applications for the design and fabrication of a reliable pellet fueling system. In rf systems, key design and development areas are rf insulators, long-pulse Faraday shields, antenna survivability, system reliability, and launcher development. Responsibility for project drawings, computer-aided design and manufacturing, a data management system, and engineering design integration are other important ORNL activities.

FMIF • The Fusion Materials Irradiation Facility (FMIF) is a new program with the potential for significant future Laboratory involvement. ORNL staff members are leading a national design team that applies the strengths of ORNL, LANL, and Argonne National Laboratory to the development of a design concept for an accelerator-based beam target system for the production of high-energy neutrons, simulating a D-T fusion spectrum. The study is expected to expand in 1994 to include international participation in a conceptual design. The Oak Ridge reservation would be an attractive site for such a facility.

Volume Neutron Source • The Advanced Systems Program has recently joined a team led by the University of California at Los Angeles to evaluate the options for a Volume Neutron Source. Starting in 1994, ORNL will provide support in the areas of concept design and configuration

development for improved maintainability and availability. The Spherical Tokamak will also be proposed as a candidate device for the Volume Neutron Source.

Technical and Scientific Applications • The application of fusion science and technologies to problems outside the fusion area has become an increasingly important part of Fusion Energy Division activities and now provides some 15% of the Division budget. Fusion technology has been successfully applied to

- waste remediation using microwaves and cryogenic pellets,
- improved materials production techniques using microwaves and rf waves,
- plasma processing of materials, and
- superconductivity development and applications.

A goal of the Division is to expand these applications by 20% a year over the next few years.

High-Energy Physics—KA

The High-Energy Physics (KA) Program at ORNL should continue to grow in the future as a result of activity related to the national Superconducting Super Collider (SSC) program. In addition to existing activity in radiation shielding design, the efforts associated with the joint experimental High-Energy Physics Program among ORNL, the University of Tennessee (UT), and other Southern Association for High Energy Physics (SAHEP) universities (in particular, Duke University and the universities of Virginia and Mississippi) are expected to increase significantly. The current high-energy physics R&D activities will continue to grow owing to the strengthening of the in-house High-Energy Physics Group and to the collaborative research initiated through the Oak Ridge Detector Center (ORDC).

Continuing Initiative

High-Energy Physics Research Program and the Oak Ridge Detector Center

Successful use of the Superconducting Super Collider (SSC) for high-energy physics investigations will require the design and construction of a new generation of detector systems in parallel with the design and construction of the SSC. Preliminary R&D has been initiated for this purpose through both DOE and the SSC Project. The two large detector systems will be major development tasks that will cost several hundred million dollars. Building these systems will involve targeting particular areas of high-energy physics and planning an associated research program; it will also require a broad multidisciplinary approach to solve the various materials, engineering, data acquisition and analysis, and physics problems associated with the detectors. Close coordination among ORNL programs and the Energy Systems Engineering organization will be required.

Collaborations between southern universities and ORNL continue under the guidance of the Southern Association for High Energy Physics (SAHEP), which is chartered under the Oak Ridge Institute for Science and Education (ORISE) and has a membership of 18 universities and other organizations, including ORNL. In addition, close ties are maintained with the Southeastern Universities Research Association (SURA). SAHEP was created both to support the SSC Project and to increase the high-energy physics base in the Southeast. The SAHEP organization acknowledged the strategic location and facilities of ORNL and recognized the importance of having ORNL play one of the focusing roles in the region.

Several close collaborations have been established between SAHEP members and ORNL. These projects are detailed in this

subsection as the Laboratory's involvement with the detector collaborations is discussed.

ORNL has a strong involvement with the Solenoidal Detector Collaboration (SDC) and the Gamma, Electron, and Muon (GEM) Collaboration. These groups are expected to produce the two large general-purpose detectors that will be ready to investigate the "new physics at 40 TeV and 10^{-19} m" when SSC becomes operational in the late 1990s. ORNL's prime responsibilities for the SDC collaboration include the design, engineering, and construction of the outer central tracking chamber; the system integration of the entire central tracker, including inner, outer, and intermediate components; and the proper internal shielding necessary to reduce the neutron background to acceptable levels. SAHEP members closely associated with this research include Duke University and Florida State University.

In the GEM collaboration, ORNL plays an important role in calorimetry and participates in the development of radiation-hardened electronics for the central tracker system. ORNL is responsible for the outer hadron calorimeter, a large (900-ton) copper/scintillating-tile sampling device. The Laboratory also participates in R&D efforts associated with the forward calorimeter system, which is designed to operate in a radiation-intense environment. SAHEP members associated with GEM include the University of Mississippi and the University of Tennessee (UT).

In addition, ORNL is strongly coupled to the Super Fixed Target (SFT) B Physics Facility for the SSC that is headed by the University of Virginia, another SAHEP member. The SFT needs support in the area of fast radiation-hardened electronics, in development and design of electronic chips, and in general in the mechanical engineering of the entire detector.

All SSC-related activities are coordinated by the Oak Ridge Detector Center (ORDC). The ORDC serves as the focal point for all science and engineering divisions involved in SSC-related research and provides an organizational interface with outside collaborators in the area of SSC detector R&D. The center's goals are (1) to establish the Southeast as a major force in high-energy physics; (2) to enhance cooperation for joint detector R&D among DOE's Oak Ridge facilities, universities, and private industries; (3) to build a technology base for the engineering, design, construction, and testing of major components of SSC-style detectors; and (4) to conduct detector R&D for other physics programs such as the Relativistic Heavy Ion Collider (RHIC) and the Advanced Neutron Source (ANS). Research areas monitored by ORDC include detector simulation; radiation damage; and electrical, mechanical, and materials engineering. Funding for these research projects comes either directly or indirectly from the DOE SSC Laboratory.

Because of ORNL's close connections with several SAHEP universities (e.g., UT, Duke University, the University of Mississippi, and the University of Virginia), a pilot program of joint appointments is being sought. These appointments, which will be similar to the current joint appointments between UT and ORNL, will provide a technical interface with the national and international high-energy physics community, additional expertise in matching detector R&D to experimental requirements, and continuing involvement of the Laboratory in the data collection and data analysis phases of the SSC program.

The nature and extent of ORNL's involvement in the SSC are evolving as the SSC program gains momentum nationally. ORNL will continue to explore and define its role in this important national initiative. ORNL's diverse multidisciplinary research programs place the Laboratory in a good position to make major contributions to numerous aspects of the SSC program. Projected funding is shown in Table 5.2.

Table 5.2
Budget projections by fiscal year for the High-Energy Physics Research Program and the Oak Ridge Detector Center[a]
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Operating expense	1.5	1.5	1.5	1.5	1.5	1.5
Capital equipment	3.5	3.5	3.5	3.5	3.5	3.5

[a]Includes funding from the SSC Laboratory. See Table 11.5 for funds being sought from the Office of Energy Research under High Energy Physics—KA.

Nuclear Physics—KB

The Nuclear Physics Program emphasizes basic nuclear physics research, both experimental and theoretical, and operation of two user facilities: the Oak Ridge Electron Linear Accelerator (ORELA) and the Holifield Radioactive Ion Beam (RIB) Facility, an upgrade of the Holifield Heavy Ion Research Facility (HHIRF) that will be operational in FY 1995. Research is carried out at these two facilities by ORNL staff and by visiting scientists from around the world. Experiments carried out at the ORELA and Holifield facilities include measurements with particle beams ranging in mass from neutrons to uranium ions and in energy from thousands to billions of electron volts.

Heavy-Ion Physics Task—KB02 • The period through FY 1994 will be an exciting and challenging one for ORNL as the accelerators of the HHIRF are modified to provide RIBs. (This project is discussed below in the section "Continuing Initiative—Radioactive Beams/Recoil Mass Spectrometer.") The transition to an RIB facility began toward the end of FY 1992 with the termination of operation of the HHIRF as a national user facility. This concluded a remarkably successful decade in which the Holifield accelerator provided 38,000 hours of ion beams for research to a large segment of the physics community.

Funding of $2.4 million is being provided by DOE for modification of the Holifield accelerator system. The cost is modest and the time for implementation is short because the required two accelerators are already in place. Light ion beams from the Oak Ridge Isochronous Cyclotron will be used to bombard a thick target to produce nuclear reactions. The resulting radioactive products will be ionized, mass separated, and then accelerated by a 25-MV tandem. Ions with atomic mass up to 80 will be produced with energies sufficient to undertake programs in nuclear structure and astrophysics. The transition to an RIB facility will be completed in FY 1995, and resumption of operation as a national user facility is planned at that time.

To capitalize fully on the potential provided by RIBs, several other tasks are being undertaken in parallel to the RIB project. Chief among these are the procurement and commissioning of the recoil mass spectrometer (RMS). A new target room will house the RMS as well as a large array of germanium gamma-ray detectors, such as the Gammasphere now under construction at Lawrence Berkeley Laboratory (LBL). The RMS, with a projected cost of $2.2 million, is jointly funded by DOE, ORNL, the Oak Ridge Institute for Science and Education (ORISE), the state of Tennessee, Vanderbilt University, UT, and several other universities. This device has unmatched capabilities for the study of very weakly produced isotopic species and is thus an excellent tool for measurement of RIB-induced reaction channels leading to proton-rich nuclei extremely far from the valley of beta stability. The RMS is now under construction, and delivery to Oak Ridge is expected in early FY 1994. A new experiment room should be ready to house the RMS at that time.

The low- and medium-energy research program includes a broad range of studies using heavy-ion beams produced at accelerator facilities around the world. Research is carried out in three

These areas overlap considerably. Research in nuclear structure is concerned primarily with the structure of nuclei at high spin and involves the study of high-spin-state spectroscopy, nuclear lifetimes, chaotic behavior in rapidly rotating nuclei, and nuclei far from stability. These areas of study will be greatly enhanced by the availability of accelerated radioactive beams at ORNL. Giant resonances in both "cold" and "hot" nuclei are the primary area of study in the nuclear reaction spectroscopy field. This includes nonstatistical effects in the giant dipole resonance (GDR) in the same compound nucleus formed via different reactions, loss of GDR strength with increasing nuclear temperature, and nuclear temperature effects in the GDR width. Nuclear collision dynamics research studies the details of the interactions between nuclei when they collide at energies from below the Coulomb barrier to several hundred million electron volts. These studies involve topics such as sub-barrier fusion, projectile fragmentation, and orbiting reactions.

Research in each category is carried out primarily on equipment developed by the research staff. Nuclear structure research uses close-packed arrays of Compton-suppressed germanium detectors. Reaction spectroscopy studies use a large array of BaF_2 scintillation detectors designed for use with photons of energy up to 300 MeV. This array, the largest of its type in the United States, has been used in 25 experiments since it became operational in 1990. A proposed major expansion of this array is particularly important to the plans for this program. Much of the study of reaction dynamics is carried out using a multielement, heavy ion/light ion detector system that can detect coincident reaction products over a very wide range of mass and energy.

At higher energies, heavy ion reactions are studied with ultrarelativistic projectiles of 200 GeV per nucleon at the Super Proton Synchrotron, located at the Conseil Européen pour Recherche Nucléaire (CERN) Laboratory for Particle Physics in Geneva, Switzerland. The primary purpose of this research is to study the production and characteristics of the quark-gluon plasma that may be formed in reactions between nuclei at these energies. ORNL plays a major role in the CERN-based WA80 collaboration as well as in the succeeding experiment, WA93. In both experiments, emphasis is placed on photon measurements. Because of their noninteracting properties, photons constitute one of the best probes of early reaction phases. ORNL built the calorimeters of WA80 and continues to operate them. Plans call for a major ORNL contribution to the photon-detection capabilities of WA93 in the form of readout electronics.

If a quark-gluon plasma is formed at the near-threshold energies of the CERN Super Proton Synchrotron, it will be a baryon-rich plasma. In contrast, energies available at the Relativistic Heavy Ion Collider (RHIC) under construction at Brookhaven National Laboratory (BNL) are expected to lead to a relatively baryon-free plasma dominated by created particles. ORNL has a leadership role on one of the two major detectors, the Photon Electron New Heavy Ion Experiment (PHENIX), under consideration for the RHIC. This detector emphasizes measurements of electrons, muons, and photons. Because of their penetration properties, the leptons are considered to be excellent probes of the quark-gluon plasma. A certain fraction of muon and electron pairs results from the decay of vector mesons, the properties of which are likely to be a good signal of creation of dense matter and of deconfinement. ORNL is in charge of a major R&D activity, the BNL-based RD-10 experiment, in support of the measurement capability of PHENIX. A cost and schedule review for PHENIX is in preparation.

Continuing Initiative

Radioactive Beams/Recoil Mass Spectrometer

A continuing initiative for the Holifield Facility is the development of the capability to produce and accelerate radioactive ion beams (RIBs). This initiative seizes on a new scientific opportunity and builds on a long-range plan to provide a world-class center for nuclear

structure physics and astrophysics at ORNL. Radioactive beams will give the Holifield Facility a unique capability for studies in these areas. DOE is providing $2.4 million for this project for the period from FY 1992 to FY 1994.

The combination of the existing Oak Ridge Isochronous Cyclotron (ORIC) and the 25-MV tandem accelerator at the Holifield facility provides the opportunity for producing a large variety of low-energy, proton-rich, radioactive heavy ion beams at modest cost. An intense light ion beam from ORIC will produce radioactive isotopes (via fusion reactions in thick targets) that will then be prepared for re acceleration in the tandem accelerator. Because both accelerators exist at Holifield, as does an appropriately shielded target room for the Isotope Separator on Line source, this offers a quick, cost-effective method for producing radioactive beams. The use of the tandem accelerator (designed to accept low-energy, negatively charged heavy ions) as the postaccelerator for the facility allows the production of beams of heavy ions up to mass 80. More than 200 new proton-rich compound systems can be produced using stable targets and the beams initially expected from the facility. Many of these are of special interest for studies in nuclear physics and astrophysics.

For full exploitation of the new scientific opportunities provided by the RIBs, some significant improvements in the experimental apparatus at Holifield should be made. The major step now under way is the procurement of a recoil mass spectrometer. Details of this device are presented in the subsection "Nuclear Physics—KB."

A large array of high-resolution gamma-ray detectors, with efficiency at least a factor of 10 greater than that of the existing Holifield detector array, is urgently needed as well. This could be realized at a cost of $17 million with the Gammasphere array now under construction at Lawrence Berkeley Laboratory (LBL). DOE has stated that the Gammasphere will be moved to a new site after 18 months of operation at LBL. The Holifield Facility is one of the two most likely sites for the relocation. However, with the probable schedule for completion, this move is not expected before FY 1996. Because an improved detection system will be needed in mid-FY 1995 for the RIB studies, it is proposed to upgrade the existing Holifield Close-Packed Array by adding 12 new, larger germanium detector modules to be used in conjunction with 12 of the existing modules (each module consists of a high-resolution germanium detector surrounded by a bismuth-germanate veto detector, with the associated electronics). This upgrade will provide the needed gain of a factor of 10 in efficiency at a relatively modest cost of $1.8 million. As shown in Table 5.3, which gives budget projections for this initiative, funds for this upgrade are requested in FY 1995 and FY 1996.

One additional major new research device is a mass separator for nuclear astrophysics studies. The astrophysics user community is expected to provide this device.

Table 5.3
Budget projections by fiscal year for development of radioactive ion beam capability at the Holifield Facility
($ in millions—BA)

	1993	1994	1995	1996	1997	1998	1999
Operating expense	3.0	3.0	3.9	4.7	5.0	5.0	5.0
Capital equipment	0.4	0.6	1.0	0.6	0.4	0.4	0.5
Accelerator Improvement Project	0.6	1.0	0.2	0	0	0	0

[a]Funds are being sought from the Office of Energy Research under Nuclear Physics—KB.

Nuclear Theory Program—KB03 • Nuclear theory centers on basic research on low-energy nuclear structure and astrophysics and on relativistic heavy ion physics. The relativistic heavy ion program provides support and guidance for the experimental programs at CERN and BNL and entails calculations with models of hadronic evolution and hadronization. Research in nuclear structure theory has expanded to take advantage of the new opportunities presented by the joint ORNL-UT nuclear structure theory program. This program emphasizes three important themes: (1) the opportunities in traditional nuclear structure physics offered by RIB physics, (2) the new interface between nuclear structure physics and nuclear astrophysics afforded by RIBs, and (3) the opportunities provided by a new generation of massively parallel supercomputers for both nuclear structure and nuclear astrophysics calculations. Studies in this area include nucleosynthesis, beta decay, numerical simulations of type II supernova explosions, and nuclear reaction calculations for proton-rich nuclei. Part of the theory activities will focus on the computational Grand Challenge on the quantum structure of matter. This project is interdisciplinary in scope and involves collaborations among nuclear, atomic, and condensed matter physics. This research will support a new level of computational nuclear structure physics, primarily to perform algorithm development and support for massively parallel calculations.

Low-Energy Nuclear Physics Program—KB04 • The Low-Energy Nuclear Physics Program supports several tasks, including operations and research at the ORELA, a unique pulsed neutron source accelerator facility for measurements by time-of-flight spectrometry of neutron cross sections and related quantities over the entire range from 0.001 eV to about 80 MeV. Funding is also provided through this program for related activities, including the evaluation of neutron cross sections for the national Evaluated Nuclear Data Base and nuclear model development.

This program provides results that are important to basic physics as well as the bulk of the nuclear data used for applied purposes in the United States. Current basic physics work provided the first nonzero value for the polarizability of the neutron and unique data on high-temperature superconductors around their critical temperatures. Work is under way to study the neutron-electron interaction. Neutron transmission, differential elastic scattering, and total inelastic, capture, fission, and neutron and gamma-ray emission cross sections are measured to meet the needs of engineers and scientists who apply nuclear information in their work.

This program also supports a vigorous effort to study the details of giant multipole resonance excitation and decay. These studies make use of accelerator facilities at the Grand Accélérateur National des Ions Lourds in France, the Indiana University Cyclotron, and the Texas A&M University superconducting cyclotron. Efforts have involved studies of two-phonon GDR states and isovector giant resonances through Coulomb excitation using medium-energy heavy ions and photon decay of the resonances. This research uses a large array of BaF_2 detectors for observation of the decay process.

Basic Energy Sciences—KC

The Basic Energy Sciences (BES) Program supports a broad spectrum of research in the physical sciences. The two largest subprograms are Materials Sciences (KC02) and Chemical Sciences (KC03). National initiatives central to this program are the Advanced Materials and Processing Program (in KC02) and the initiative in Advanced Manufacturing (in Engineering and Geosciences, KC04). Key issues facing these subprograms include development of the ANS and the Materials Science and Engineering (MS&E) Complex (see Sect. 4, "Summary of Major Initiatives").

Materials Science—KC02 • The Materials Sciences subprogram supports fundamental materials R&D including neutron scattering; synthesis and characterization of new materials; high-temperature materials; ceramic processing; superconductivity; ion beam, laser, and plasma processing; and theoretical studies for advanced energy-related materials. This subprogram also supports a number of user facilities, including the Surface Modification and Characterization/ Collaborative Research Center (SMAC/CRC), the Shared Research Equipment (SHaRE) Program, the

National Center for Small-Angle Scattering Research, and the neutron scattering research facilities at HFIR. These facilities had over 300 guest users in FY 1992. Two of the Laboratory's major initiatives are in the materials sciences: ANS and the MS&E Complex, both discussed in Sect. 4, "Summary of Major Initiatives." The Advanced Materials, Design Methods, and Manufacturing Technology initiative will also draw on resources in this area. KC02 funding is expected to increase sharply during conceptual design and construction of ANS, although the core program is not expected to grow during this period.

Metallurgy and Ceramics Program—KC02 01 • The Metallurgy and Ceramics Program of the Division of Materials Science (DMS) funds a wide range of research activities in the ORNL Metals and Ceramics (M&C) Division and a new 2% Initiative in the Solid State Division. This program provides a fundamental framework for fostering the development of innovative materials and processes. The overall goal is to develop an understanding of materials and material processes at all levels, from the atomic structure to the macroscopic properties. The program includes the research components required for better understanding and use of materials: synthesis, processing, fabrication, characterization, and development of models/mechanisms. In 1993, as the result of consolidation actions within the Office of Basic Energy Sciences (DOE-BES), the X-ray diffraction program in the M&C Division was transferred to join the other synchrotron research programs funded by DOE-BES in the Solid State Physics Program (KC02 02).

Research in synthesis and processing science includes the development of fabrication and joining techniques for advanced intermetallic alloys, ceramics, and composite structures. Intermetallics research includes fundamental studies of phenomena related to physical and mechanical properties, ranging from atomic bonding to environmental embrittlement. Investigations in the ceramics program are focused on the establishment of relationships between basic microstructure and properties for the design of advanced ceramics and ceramic composites, including self-reinforced silicon nitrides. A strong first-principles theory effort is integrated with the alloy development program. Expansion of the theory program to include a first-principles ceramics theory effort is planned.

The welding program continues to investigate the evolution and stability of microstructures and properties of weldments, including mathematical modeling and experimental verification of transport phenomena. This task includes serving as the coordinator for the national BES Welding Program.

Important to all of the tasks are the development and application of advanced characterization techniques, including analytical electron microscopy, atom probe field ion microscopy, the mechanical properties microprobe, and ion beam techniques. Ion implantation is used to study defect interactions and radiation effects and to modify surface-related properties of polymers and ceramics. New techniques and facilities for high-temperature mechanical properties microprobe studies and the three-dimensional multielement atom probe are near completion. New instrumentation to be added during FY 1993 includes a new 200-kV field emission gun analytical microscope to replace a 14-year-old instrument, an advanced analytical scanning electron microscope, and an atomic force microscope (to be added to the mechanical properties microprobe facility). A new 2% Initiative has been funded for the study of atomistic mechanisms at interfaces with Z-contrast direct atomic imaging and theoretical simulations. A major program initiative related to our characterization efforts is the Center for Advanced Microstructural Analysis (CAMA), part of the MS&E complex, which would provide facilities designed for the specific requirements of modern analytical equipment.

Emphasis on radiation effects continues to increase, especially in the area of the effects of neutron environments. In the past two years, the program has made major contributions to the understanding of mechanisms for embrittlement of reactor pressure vessels. Fundamental studies of pressure vessel phenomena are jointly sponsored by DOE and the Nuclear Regulatory Commission (NRC).

The DMS-supported programs in the M&C Division continue to play an active role in industrial collaborations and technology transfer. All tasks have contributed to active cooperative

R&D agreements (CRADAs) or to CRADAs that are in various stages of negotiation. Our intermetallics and ceramics efforts continue to have active licensing activities.

Through ORNL and ORISE, DOE-BES supports the SHaRE cooperative research program and the Oak Ridge Synchrotron Organization for Advanced Research (ORSOAR). The SHaRE program gives scientists from universities, industry, and other national facilities access to facilities in the M&C Division, especially the analytical electron microscopes, the atom probe field ion microscopes, and the mechanical properties microprobe. The ORSOAR program supports an X-ray beam line at the National Synchrotron Light Source at BNL. This facility is used for cooperative research by scientists from more than 20 universities and industrial institutions.

Solid State Physics Program—KC02 02 • The Solid State Physics Program spans basic and applied research. Existing expertise will be directed to continuing and new basic research for the Advanced Materials and Processing Program. Applied research is under way in CRADAs with Eveready Battery Company on lithium microbatteries, the Electric Power Research Institute (EPRI) on polycrystalline silicon photovoltaics, Commercial Crystal Laboratories on the growth of large MgO crystals, Marlow Industries on thermoelectric devices, and IBM on metal deposition in fabricating integrated circuits.

Unique facilities at ORNL are used to investigate a variety of research problems in condensed matter physics/materials science. The intense neutron beams available at HFIR are used in programs on interatomic interactions in condensed systems, structure and dynamics of energy-related materials, and, through a new initiative, structures of anisotropic colloidal materials. The Small-Angle X-Ray Scattering Program supports these activities. Materials prepared by a number of researchers, both at ORNL and elsewhere, are investigated at these user facilities. The extensive ion beam facilities of the SMAC/CRC are used to characterize and alter the near-surface region of a wide range of materials. The Ion Beam Analysis and Ion Implantation Program uses these facilities, as do collaborators from several ORNL divisions and numerous universities and industries.

The Semiconductor Physics and Photovoltaic Materials Program is concerned with the processing and investigation of multilayer semiconductor and superconductor films and with the preparation of high-efficiency solar cells. The Properties of Advanced Ceramics Program studies single-phase and composite electrolyte and electronic ceramic materials in thin-film and bulk forms. The Synthesis and Properties of Novel Materials Program prepares and characterizes a variety of research specimens for study in the Solid State Division and throughout the materials science subprogram (KC02). The Surface Physics Program investigates the atomistic structure of the surfaces of metals and alloys and measures their electronic and vibronic properties. The Structural Properties of Materials—X-Ray Diffraction and the Electron Microscopy of Materials programs use a variety of sophisticated techniques to characterize materials associated with all the solid-state physics programs. Superconductivity research is centered in the Physical Properties of Superconductors and the Superconductors with High Critical Temperatures programs, but much research on this subject is carried out in many groups in several divisions at ORNL. The principal task of the Theory of Condensed Matter Program is to ensure a firm theoretical basis for the experimental programs.

In February 1992, the HFIR passed its second hydrostatic pressure test, thus providing assurance of continued safe operation of the pressure vessel. The neutron scattering user program is active, and steps are being taken to improve the visibility of this program within the scientific community. As a prelude to ANS, efforts have been made to nucleate neutron scattering programs within different research divisions at ORNL using Laboratory Directed R&D (LDRD) funds. Members of the M&C and Solid State divisions are engaged in a successful collaboration on residual stress, and a proposal to expand this program with joint support from the DOE Office of Energy Efficiency and Renewable Energy (DOE-EE) and DOE-ER has been submitted. Similarly, a joint program between the Biology and Solid State divisions is aimed at improving and using existing instrumentation for problems of biological interest.

The new 300-kV scanning transmission electron microscope has been delivered and will be extensively used in a new initiative on Atomistic Mechanisms in Interface Science (KC02 01

program). This program will provide a close coupling between direct imaging on an atomic scale and theoretical modeling in an effort to enhance our ability to synthesize new, useful materials.

Preparations for research, instrumentation, and user programs related to the ANS project will receive a high priority. Superconductor research will emphasize continued use of unique materials preparation and characterization capabilities to investigate fundamental issues in critical currents and quantum behavior. Unique capabilities in high-energy (millions of electron volts) and low-energy (tens of electron volts) implantation, laser ablation, supersonic molecular beams, plasma processing, and nanophase materials preparation will form the basis for a new research thrust on the synthesis, processing, and fabrication of advanced materials. Progress in the development and application of submicrovolt-resolution X-ray diffraction and high-resolution surface spectroscopies will continue.

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

Chemical synthetic approaches to advanced inorganic materials emphasize composition, purity, and morphology. Tailored inorganic and organometallic precursor compounds and polymers are being developed whose thermal or plasma-enhanced decomposition leads to nonoxide ceramics in thin film or fibrous forms. The discovery of novel synthetic approaches to transition metal nitride whiskers has generated a more general interest in morphostatic gas-solid reactions. Ion implantation preparative techniques, photoacoustic spectroscopic characterization, and electrochemical behavior are being combined in fundamental studies of electrocatalysis by mixed-oxide overlayers on metals.

A dual focus exists in the area of nucleation, growth, and transport properties. The first aspect is developing an understanding of the nucleation and growth of precipitation processes of ceramic precursors. The second involves developing reactors and reactions that will lead to the reproducible production of pure and mixed ceramic precursors. Because the transport properties of the species involved in these processes have theoretical and process importance, diffusion coefficients and viscosities are being measured.

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

Understanding the relationships among molecular structure, processing conditions, and performance properties of modern organic polymeric materials poses a unique challenge to structural chemists. Techniques being applied include neutron and X-ray scattering for both semicrystalline fibers and largely amorphous polymers and model compounds, neutron spectroscopy, thermal analysis, solid-state nuclear magnetic resonance (NMR) spectroscopy, scanning tunneling and atomic force microscopy, and molecular dynamics simulations. Used in combination, these techniques are revealing often unexpected microstructural and dynamic features, particularly in the semirigid parts of polymer systems.

A new initiative is testing a new theory of polymer interactions for prediction of compatibility in nanoscale polymer blends; small-angle neutron scattering is the key experimental tool in this work. This polymer research benefits from the presence of an ORNL-UT Distinguished Scientist.

Chemical Sciences—KC03 • The Chemical Sciences Program supports the HFIR; the Radiochemical Engineering Development Center (REDC); and programs in atomic physics, basic chemistry, and chemical engineering.

HFIR • Neutrons from HFIR are vital to many research projects in the materials sciences, chemical sciences, magnetic fusion, and biology programs at ORNL and for users and collaborators

from many universities, laboratories, and industries. HFIR offers a unique combination of high flux, a mixed thermal/fission neutron spectrum, low irradiation temperatures, and flux tailoring. It is essential to neutron scattering experiments, isotope production, and studies of material damage and to the design of advanced reactor concepts such as the ANS. It is also one of the world's most powerful facilities for neutron activation analysis.

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

The DOE Transuranium Element Processing Program, the main program at the REDC, produces and distributes rare isotopes of the transuranium elements, including ^{248}Cm, ^{249}Bk, ^{249}Cf, ^{252}Cf, ^{253}Es, ^{254g}Es, ^{255}Fm, and ^{257}Fm. The sequential process used to produce these isotopes includes (1) fabrication of curium targets in the REDC hot cells, (2) irradiation of the targets in HFIR, and (3) remote processing in the REDC to separate and purify each of the heavy elements and to package the individual products for shipment. Researchers, located primarily at ORNL, Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), LBL, and Argonne National Laboratory (ANL), use the heavy transuranium elements and their isotopes for R&D in nuclear chemistry, inorganic and solid-state chemistry, nuclear physics, nuclear medicine, and other areas. Recently, 13 different research groups within 8 DOE laboratories have been users of the heavy element isotopes, collaborating with 17 universities and 10 international research institutions, and supporting approximately 120 scientists, technicians, and students. The Heavy Element Research Program is sponsored by the DOE-BES Division of Chemical Sciences and has been endorsed twice in the last decade by the National Academy of Sciences.

The Mark 42 Processing Program, which is sponsored in part by the Assistant Secretary for Defense Programs (DOE-DP), involves the recovery and purification of transuranium element isotopes (^{242}Pu, ^{243}Am, and ^{244}Cm) from Mark 42 targets that were previously irradiated at the Savannah River Site (SRS) and segmented at Pacific Northwest Laboratory. The Mark 42 targets are processed to recover light transuranium element isotopes for use in weapons diagnostics at LANL and LLNL. Approximately one Mark 42 target will be processed each year in the REDC at ORNL for about 10 years. Processing began in 1991.

As a coproduct of the Heavy Element Research Program, REDC activities provide ^{252}Cf neutron sources, which can be used in neutron radiography, neutron activation analysis, and cancer therapy. The ^{252}Cf Industrial Sales/Loan Program, also sponsored in part by DOE-DP, is carried out to fabricate these neutron sources. Neutron source capsules are fabricated in a variety of configurations and source contents (strengths) ranging from 1 μg to 50 mg of ^{252}Cf. Currently, more than 230 sources are on loan for uses in medical therapy or research, teaching or demonstration at universities, and industrial applications. About two-thirds of the sources in industrial applications are used by DOE offices or integrated contractors; the remainder are used by other agencies of the federal government. Bulk ^{252}Cf is also supplied to commercial neutron source fabricators. This work is done in the REDC Californium Facility in Building 7930.

Other REDC projects and capabilities include a wide variety of special radioisotope preparations, "hot" chemistry experiments in support of the U.S. program for partitioning and transmutation of actinide elements from high-level wastes, and "hot" experiments in support of existing and future DOE liquid waste pretreatment and management programs. An educational capability also exists at the REDC for B.S., M.S., and Ph.D. students in the areas of radiochemistry, accelerator target development, reactor target development, integral neutron cross-section measurement, and radiochemical processing. This capability could be used to enhance efforts of the Seaborg Transactinium Institute in training students interested in transactinium research.

Funding for the major programs currently carried out at the REDC is ~$14 million per year. Of this amount, DOE-ER provides ~55%; DOE-DP, ~43%.

Atomic Physics, Basic Chemistry, and Chemical Engineering • The Atomic Physics Program at ORNL encompasses both experimental and theoretical investigations of a broad class of phenomena occurring when multiply charged heavy ions interact with gases, solids, free and bound electrons, photons, and other ions. This program currently operates the EN Tandem Accelerator, a user facility that provides a wide variety of light ions and multiply charged heavy ions at energies up to several million electron volts per nucleon. Members of the atomic physics group are also collaborating on a new series of atomic studies with ultrarelativistic heavy ions at CERN. At the other end of the energy spectrum, experiments on cross sections for inelastic collisions of multicharged ions with neutral atoms and molecules are carried out at the lowest attainable energies and are currently conducted using the ORNL electron cyclotron resonance (ECR) ion source. Studies of collisions of multicharged ions with multicharged ions have been initiated, and a new program is proposed to study details of ion-surface interactions. These studies emphasize characterizing the energy and angular distribution of ejected electrons. The ECR source provides beams for merged- beam experiments. The merged-beams apparatus and the techniques currently being developed are applicable to the study of ion-atom chemical reactions involving unstable or reactive atomic species. An upgrade of the ECR source that provides significantly improved performance for this facility has been completed.

The atomic theory program studies atomic collisions over a wide range of energies using powerful new mathematical and computational methods. Particular attention is focused on complex systems, such as highly charged ions, which play a leading role in many branches of energy research. This program interacts strongly with the experimental atomic collision programs at ORNL and other laboratories. This group has pioneered the theory of atomic collisions at ultrarelativistic energies, which provided the motivation for experiments at CERN, BNL, and LBL. Many applications rely on access to supercomputers, notably the CRAYs at the National Energy Research Supercomputer Center and the massively parallel Intel Paragon at the ORNL Center for Computational Sciences, and much effort has been devoted to developing algorithms that efficiently use the features of these architectures. The Center for Computationally Intensive Physics, a collaboration involving ORNL, UT, and Vanderbilt University, partially supports these activities. This Center is part of a consortium that will use the Intel Paragon, which constitutes a unique resource for theoretical atomic physics. It is interdisciplinary in scope, with collaborations in atomic, nuclear, and condensed matter physics.

Basic chemistry studies of the actinides and transactinides emphasize the elements (curium and elements of higher atomic number) that are uniquely produced at the HFIR and the REDC or from HFIR products. The goal is elucidation of the systematic trends in behavior of the characteristic 5f electrons progressing across these heaviest elements in the periodic table. Increased emphasis is being placed on relevance to nuclear waste and remediation issues. Experimental approaches to define the chemical and solid-state properties of these elements and their compounds include structural studies at high pressures and temperatures, characterization of unusual oxidation states in high-temperature vapors, absorption and luminescence spectroscopic studies of solutions and solids, and magnetic and heavy fermion behavior at low temperatures. Solution properties are studied as an adjunct to the effective separation of the HFIR products. Fundamental mechanisms related to separations are studied by low-temperature matrix spectroscopy and other methods; emphasis is placed on exploiting photochemistry and coordination chemistry for separations purposes. State-of-the-art relativistic quantum mechanics calculations are carried out to complement experimental studies. ORNL is also involved in a multilaboratory initiative to establish a beam line at the LBL Advanced Light Source dedicated to actinide science; ORNL interest is focused on electronic characterization of gas-phase actinide species.

During FY 1992, a new Inorganic Mass Spectrometry Laboratory was completed at the main ORNL site and occupied by researchers formerly housed at the Oak Ridge Y-12 Plant. Concurrently, modifications to the Transuranium Research Laboratory were initiated; when completed, these will allow our actinides mass spectrometry activities to be moved to the main ORNL site. These new

facilities, plus the Organic Mass Spectrometry Laboratory completed in FY 1989, constitute a diverse collection of modern mass spectrometry instrumentation that will significantly enhance our collaborative research and educational activities.

ORNL conducts fundamental research in numerous analytical methodologies, such as

- glow discharge inorganic mass spectrometry,
- ion trap mass spectrometry,
- laser-based optical and mass spectrometry,
- detection of explosive and other hazardous vapors,
- electrospray-based organic mass spectrometry,
- gas phase ion chemistry,
- secondary ionization mass spectrometry,
- positron spectrometry, and
- biological mass spectrometry.

Single molecules of fluorescent compounds have been detected by levitating microdroplets in an ion trap and examining them via laser-based fluorescence spectrometry. This technique has provided fundamental insights into optical behavior of microdroplets, and it enabled the detection of single molecules of target compounds.

A unique array of complementary experimental and modeling techniques is applied to study thermodynamics of interactions and reactions in highly nonideal aqueous solutions of electrolytes at high temperatures and pressures, especially near the critical point of water. The systems studied are selected for their fundamental significance and for their relevance to energy-related technologies including steam generation, nuclear and chemical waste disposal, the extraction of heat and mineral resources, and hydrothermal geochemistry. In fact, many components of the KC03 basic chemistry program are well positioned to contribute fundamental chemical information that is relevant to the growing national emphasis on environmental remediation and protection and associated waste-related R&D, especially for aqueous systems.

Research in surface science/heterogeneous catalysis gives special emphasis to questions of surface structure and reactions involving sulfur-containing species on metals and surface alloys that serve as models for commercial hydrodesulfurization catalysts. Several ultrahigh-vacuum surface structure approaches (including low-energy ion scattering) and surface reaction approaches are employed, including synchrotron-based spectroscopies to characterize molecular adsorbates.

Obtaining new molecular-level knowledge concerning the organic chemical structure and reactivity of coals is an area of continuing emphasis. These studies highlight the application of solid-state NMR techniques to chemically modified coals and the use of surface-immobilized compounds to simulate diffusional restrictions during thermal and catalytic processing of coal. The information derived from these fundamental studies will contribute to the development of novel and environmentally sound processes for the use of coal as a source of liquid fuels, chemicals, and clean energy.

Chemical and physical principles underlying the design of more effective multiphase separation processes are being defined. The concept of molecular recognition is being applied in the design, synthesis, and evaluation of novel ligands for separating closely related metal ions by solvent extraction. Incorporation of complexing ability, charge-neutralizing ability, and organophilicity into single multifunctional extraction agents is currently stressed. A new emphasis on selective extraction of ion pairs is emerging.

Studies of the photochemical reactions and associated photophysics of aromatic molecules address atypical media such as aqueous solutions and sorbent solids. In addition to elucidating fundamental questions of photoreactivity in anisotropic environments, this work should contribute to understanding the transformation of hazardous materials in natural settings exposed to sunlight.

Research on the kinetics of enzyme-catalyzed processes will concentrate on the fundamental physicochemical aspects of the conversion of light energy into chemical energy using artificial photosynthetic systems and the mechanisms associated with enzyme solubilization of cellulose and

lignin. This research is directed at synthesizing a simplified photosystem that can produce fuel from renewable resources and understanding the bimolecular optoelectronic properties of metallized photosynthetic membranes.

Developing a better fundamental understanding of transport phenomena involving drops, bubbles, and films is essential for achieving future improvements in the efficiency of diverse multiphase separations processes. Moreover, recent research has shown that electromagnetic fields can drastically enhance the rates of momentum, heat, and mass transport in fluids containing small drops, bubbles, and particles. Therefore, the main goal of our research on principles of multiphase separations is to explore, by means of experimental, theoretical, and computational studies, the fundamental issues and the enhancement of transport phenomena by external electromagnetic fields as they relate to liquid-liquid, liquid-vapor, and liquid-solid separations. Current research emphasizes studies of the dynamics of single drops and pairs of drops. Representative problems under investigation include oscillations of liquid drops, drop and bubble formation in an ambient flow field, and drop breakup and coalescence.

Fundamental, experimental, and theoretical studies of the interactions of solvents, solutes, and surfaces relate macroscopic properties of solutions to intermolecular interactions and molecular correlation functions for challenging and important systems such as those characteristic of extraction by, and adsorption from, supercritical solutions. These studies use methods such as distribution function theories, fluctuation theory, molecular simulations, and neutron scattering.

Continuing Initiative

Development of Melton Valley as a Strategic Resource for Nuclear and Radiochemical Technology

An initiative is proposed to revitalize nuclear research at ORNL for the next century by integrating existing, planned, and some new process and support facilities in Melton Valley into a focused major nuclear research center that will support DOE's long-term nuclear and radiochemical R&D activities. Budget projections for this initiative are given in Table 5.4. Creation of the Melton Valley Nuclear and Radiochemical Research Center would ensure continued capability to support DOE Office of Energy Research (DOE-ER) missions at the High Flux Isotope Reactor (HFIR) and the Advanced Neutron Source (ANS) and other critical nuclear research missions. Such a center could also play an important role in educating and training nuclear scientists and engineers.

Near-term activities are focused on a detailed assessment of future U.S. nuclear technology needs and the potential roles of this center in fulfilling those needs. These activities will aid in visualizing and developing the general concept into a framework for the future of nuclear research at ORNL.

The major existing nuclear facilities in Melton Valley, the HFIR and the Radiochemical Engineering Development Center (REDC), would be integrated into the center. Existing and anticipated missions for the REDC include production and purification of heavy elements, radioactive waste management R&D, fuel cycle and fission product research, and support of some weapons activities for the Assistant Secretary for Defense Programs (DOE-DP).

Major new facilities now planned in Melton Valley include the ANS and a complex of facilities for collection, treatment, packaging, and storage of existing and future nuclear wastes. Other facilities, such as a 14-MeV neutron source for the development of fusion materials, are also being considered.

Other nuclear facilities at ORNL provide important programmatic support in inspection of radioactive materials and radiochemical process capabilities, such as

limited isotope production. As these older facilities are phased out, some of their capabilities will remain critical to an overall comprehensive center. Replacements should be built early in the next century in Melton Valley. Careful planning and development of a comprehensive center would optimize the value of the large capital investments already planned in Melton Valley and minimize the additional investment required to sustain the critical inspection and radiochemical process capabilities needed within DOE to support programmatic work. Developing these facilities into a center in Melton Valley would also permit the eventual location of all of ORNL's hazardous facilities within that valley and away from the central Bethel Valley location.

The Melton Valley center would provide extensive capabilities for R&D in support of programs in DOE's Office of Environmental Restoration and Waste Management (DOE-EM) to meet decontamination and decommissioning needs and, in resolution of other radioactive waste-related problems, would ensure continued capability to carry out DOE-DP missions that are under way and anticipated for the REDC. The center would also enhance the educational opportunities in radiochemistry and radiochemical processes available to the next generation of scientists and engineers and would position ORNL to support DOE's future needs for nuclear energy R&D.

Table 5.4
Budget projections by fiscal year for the development of Melton Valley as a strategic resource for nuclear and radiochemical technology[a]
($ in thousands—BA)

	1994	1995	1996	1997	1998	1999
Total funding	500	500	1000	1000	2000	2000

[a]Funds are being sought from the Office of Energy Research under Basic Energy Sciences—KC and from the Office of Nuclear Energy under Nuclear Energy R&D—AF.

Continuing Initiative

Center for Excellence in Research Reactors

A Center for Excellence in Research Reactors (CERR) is proposed to stimulate increased use of research reactors and to help make these facilities more accessible and user friendly. The CERR will build on strengths in existing research reactor activities at ORNL, other DOE sites, and non-DOE facilities and will benefit both users and operators of research reactors.

The CERR will gather, process, and distribute information about research activities and reactor operations by creating a database on research programs and reactor facilities throughout the United States. In addition, it will serve as a bridge between users and operators of research reactors and act as a catalyst for increasing beneficial interactions among reactor operators.

The CERR has three synergistic objectives:

- To increase use of research reactors by identifying innovative uses of these facilities and informing prospective users of opportunities available to them at these reactors. It will also promote modifications and/or additions to research reactors to improve their usefulness to users.
- To provide technical support to research reactor users by creating and maintaining a database on user-oriented features. It will also maintain software systems and involve personnel who can perform technical analyses for the users and provide specialist contacts on specific issues.
- To foster excellence in research reactor operations, both by stimulating exchanges

of "good practices" and "lessons learned" among reactor operators and by encouraging operators to participate in "common element" activities. As an example, the CERR will support interactions between research groups and operational groups (e.g., the Association for Excellence in Reactor Operations) that are focused on promoting excellence in all aspects of operations.

These objectives can be accomplished by a relatively modest effort [less than two full-time equivalent (FTE) staff members per year] to compile and provide user-oriented information about research reactor facilities and to stimulate mutually beneficial activities within the research reactor community.

Research reactors played a vital part in the development of nuclear science and engineering, and they have been essential to the development of nuclear energy throughout the world. However, more than half of the nearly 100 research reactors built in the United States during the 1950s and 1960s have been shut down. Owing to decreased use during the last decade, inadequate funding for modernization, and more rigorous operating requirements, many others may soon be closed.

The continued rapid loss of research reactor facilities could seriously affect research programs in many technical disciplines. Traditional uses for research reactors (e.g., neutron radiography, activation analysis, medical isotope production, biomedical irradiations, materials studies, and commercial product preparations) are expected to continue. In addition, exciting work remains to be done, including research in advanced ceramics and high-temperature superconductors. Researchers will need facilities that can provide the proper combination of radiation fields, sample space, temperatures, and other parameters.

The decline in the number of U.S. research reactors and the growing need for such facilities in the future present a real national dilemma. In addition, there has been no institutional means for identifying present and projected needs for research reactors and developing an integrated strategy for meeting these needs. As a result, many researchers have no reliable source of information about reactor facilities.

The organization of a CERR is a positive step toward remedying this situation and reestablishing U.S. leadership in nuclear technology. Specific activities of this program will include

- determining present and future user needs for research reactor facilities;
- collecting, analyzing, evaluating, and maintaining data on existing research reactor facilities;
- developing a unified strategy for establishing and maintaining a viable network of research reactor facilities;
- establishing and maintaining a regional center at ORNL to identify and meet the needs of the user community and to stimulate use of research reactors; and
- establishing and maintaining a regional center at ORNL to promote excellence in all aspects of research reactor operations.

Our aim is to complete the first three activities during the program's first year. In the second year, other regional centers could be established as institutional entities whose purpose would be to further increase communications and interactions with the user community.

The CERR should encompass all U.S. research reactors at universities and national laboratories and involve individuals from throughout the nuclear technology community, including representatives of industrial users. The Center will have no operational responsibilities; full responsibility for operating each reactor in compliance with applicable orders or regulations will remain with the owners and operators.

ORNL is especially well suited to initiating the CERR because of the Laboratory's strong commitment to excellence in operation of research reactors, established history of providing technical support for reactor users, and proximity to a diverse community of research reactor users. This combination is unique among DOE sites.

The CERR will provide a variety of benefits. The user community will gain easier and more cost-effective access to research reactors. Reactor operators will benefit from

increased use of facilities and from cost-effective improvements in operating standards. The CERR will greatly expand educational opportunities for students and for professional staff members of national laboratories, private companies, and governmental agencies; it will also provide an effective channel for transferring technology from government-sponsored research programs to private industries.

Table 5.5 provides budget projections for the ORNL CERR. They are also included in the ORNL budget submission summarized in Sect. 11, "Resource Projections" (Table 11.5).

Table 5.5
Budget projections by fiscal year for ORNL's Center for Excellence in Research Reactors[a]
($ in thousands—BA)

	1993	1994	1995	1996	1997	1998	1999
Total funding	0	0	406	423	453	470	485

[a]Funds are being sought from the Office of Energy Research under Basic Energy Sciences—KC and from the Office of Nuclear Energy under Nuclear Energy R&D—AF.

Continuing Initiative

Retention of the Pool Critical Assembly

A proposal has been made to DOE to retain the Pool Critical Assembly (PCA) to support training and education for a number of users, including the University of Tennessee, Louisiana State University, Mississippi State University, DOE, and ORISE, in support of DOE's mathematics and science education initiatives.

The PCA was formerly used to provide hands-on educational experiences for nuclear and military professionals. Its simple, basic structure lends itself to easy comprehension of fundamental reactor principles. Training experiences possible at the PCA include

- hands-on core assembly;
- hands-on reactor startup and shutdown;
- reactivity determinations;
- neutron spectral measurements;
- measurements of the spatial dependence of neutron absorber worth, neutron importance, and power density; and
- neutron activation analysis.

PCA-enhanced training programs will provide increased professional capabilities for nuclear engineering students and nuclear specialists (e.g., DOE Reactor Operations professionals and nuclear industry personnel). As outlined in Table 5.6, funding is requested to relocate, restart, and operate the PCA.

It is proposed to relocate the PCA to Building 7930 of the Radiochemical Engineering Development Center (REDC) at ORNL. The fuel and core assembly will occupy a 2.4- by 3.6-m (8- by 12-ft) area in the north end of an existing californium storage pool. A 110-m^2 (1200-ft^2) annex will be required to house training facilities, work areas, and the PCA control room. General plant project (GPP) funding will be requested for the control room annex.

The restart plan will contain a work breakdown structure detailing all tasks required for restart. Restart activities will require funding in FY 1994 and FY 1995.

After restart in FY 1996, operations will require about $300,000 annually, part of which will be provided by the HFIR training section. The PCA will become a part of the REDC complex; however, REDC will not provide any funding, and a fair share of utility usage and pool demineralization costs will be paid by PCA.

Table 5.6
Budget projections by fiscal year for Retention of the Pool Critical Assembly[a]
($ in thousands—BA)

	1993	1994	1995	1996	1997	1998	1999
Total funding	0	550	682	417	330	340	340

[a]Funds are being sought from the Office of Energy Research under Basic Energy Sciences—KC and from the Office of Nuclear Energy under Nuclear Energy Research and Development—AF.

Engineering and Geosciences—KC04 • The major effort sponsored by the engineering component of the Engineering and Geosciences Program is the Center for Engineering Systems Advanced Research (CESAR).

CESAR will continue fundamental research in intelligent machines, specifically in the areas of cooperation among multiple robots, sensor-based mobile manipulation, and learning for sensory motor control systems. Results from this core research program will continue to have significant ramifications for a number of applications and applied programs, including those focusing on environmental restoration and waste management and emerging programs in support of advanced manufacturing initiatives, as well as information processing activities.

The CESAR facilities include a state-of-the-art high-performance computing environment; numerous sensor systems, including multispectral vision sensors and laser range cameras; robot manipulators; and several mobile robots, some custom-built at ORNL (the HERMIES series) and others commercially available but customized at CESAR with sensors and computer control. This DOE-BES investment is being leveraged and augmented by support from a number of sponsors that target various applications of robotics and intelligent systems. With support from the Office of Nuclear Energy (DOE-NE), we have been performing applied robotics research and systems integration and have provided overall coordination and management of a consortium of four university research groups (the University of Tennessee at Knoxville and the universities of Florida, Michigan, and Texas) in a program aimed at robotics for advanced nuclear power stations. Advanced intelligent machine and robotics technology development has also been performed using the CESAR facilities and expertise for a large multilaboratory program in robotics for environmental restoration and waste management funded by the Assistant Secretary for Environmental Remediation and Waste Management (DOE-EM). The DOE Office of Health and Environmental Research (DOE-OHER) supports informatics and computational biology R&D that focuses on pattern recognition, database design and management, and data analysis and interpretation for genome-related applications.

Non-DOE sponsors include the Department of Defense and the National Highway Transportation Safety Administration. Most recently, the Office of Naval Research provided support for a new Center for Neural Engineering. Tennessee State University (TSU), a historically black university in Nashville, Tennessee, is the lead organization for this center, which encompasses a pioneering teaming arrangement among TSU, ORNL/CESAR, Meharry Medical School in Nashville, and Accurate Automation Technologies, a high-technology company in Chattanooga, Tennessee. The Center makes use of the special CESAR facilities in robotics and intelligent systems to provide research and educational experiences to faculty and graduate students from the consortium participants. Efforts to apply CESAR expertise to new initiatives in advanced manufacturing are under way.

CESAR activities continue to show results in the technology transfer arena. Two patents were filed recently, and numerous visitors and guest researchers from the United States and other nations collaborate with CESAR researchers.

The Geosciences Program concentrates on the fundamental geochemical processes that control elemental and isotopic distributions in the earth's crust. Special facilities for the study of high-temperature aqueous and magmatic systems are used to investigate acid ionization and metal ion complexing reactions, mineral solubilities and crystallization, stable isotope exchange with minerals, and the thermodynamics of the carbon-hydrogen-oxygen system at extreme conditions. Experimental data are used to model the evolution of natural systems pertinent to DOE geothermal and hydrocarbon energy programs. A unique ion microprobe capability to conduct trace element and isotope distribution systems is being applied to mineral assemblages.

Advanced Energy Projects—KC05 • The Advanced Energy Projects (AEP) Program supports exploratory research in materials and chemical sciences at moderate levels; the typical project duration is three years. ORNL initiatives include projects in electric-field-driven ceramic precursor reactors, the elucidation of enzyme hydrolysis mechanisms for wastepaper conversion to chemicals, and novel composite coatings for high-temperature friction and wear control. A new activity during FY 1992 was organization of a workshop on behalf of AEP; the topic was "Innovation in Materials Processing and Manufacture: Exploratory Concepts for Energy Applications."

Applied Mathematical Sciences—KC07 • The Applied Mathematical Sciences Program supports research in parallel processing algorithms and the development of applied mathematical, statistical, and computational methods for analyses of physical processes. These research activities are supported by an Advanced Visualization Laboratory that provides research computers with a variety of architectures in various stages of development. Parallel computers currently in the Advanced Visualization Laboratory include an Intel iPSC/2, an nCUBE/4, a Sequent Balance 8000, and an Intel iPSC/860 supercomputer. The iPSC/860 has 128 processors and a peak rating of 7.6 gigaflops. Visualization workstations include a Silicon Graphics Crimson Reality Engine and two Silicon Graphics Indigo Extremes. Recording and printing equipment enables the presentation of research results on video and slides.

The following will continue to be major research areas: sparse matrix computations, performance characterization, basic matrix computations, data analysis, design and analysis of computational experiments, and the analysis and numerical solution of partial differential equations. Pervasive in this research is the requirement for parallel processing and related software tools to meet the computationally intensive needs of today's computer models. The Grand Challenge research being conducted as part of the High-Performance Computing R&D initiative described in Sect. 4, "Major Laboratory Initiatives," is heavily dependent on the KC07 program.

Groundwater modeling is one of the Grand Challenges selected by DOE because of its importance in evaluating strategies for groundwater contamination and groundwater remediation. New groundwater codes will be developed on parallel computers that allow greater complexity in processes as well as scale. By examining site-specific problems, different simplifying assumptions can be tested and different remediation strategies can be evaluated. These are important steps in saving time and cost for groundwater cleanup by picking effective modeling and remediation techniques. The expertise developed in the Applied Mathematical Sciences Program is one of the key foundations for this activity.

A second Grand Challenge problem is in the first-principles simulation of materials properties. The goal is to allow existing quantum and statistical mechanics codes currently restricted to tens of atoms to be scaled up to thousands of atoms. This scaling will require the use of sophisticated numerical techniques that scale up as the cube of the number of atoms.

Computer Hardware, Advanced Mathematics, and Model Physics (CHAMMP), a DOE program in atmospheric and climate research (KP05), benefits from the basic program in KC07 and drives some of the latter's research activities. The program requires new parallel computing research in numerical methods; software tools; software engineering; statistical analyses; and data storage, retrieval, and visualization. ORNL's researchers in the KC07 and KP05 programs work together to apply the required expertise.

Energy Research Analyses—KD

ORNL provides support to DOE-ER in technical and economic assessments of alternative energy sources for selected sectors of the U.S. economy. The funding level varies according to the specific needs of DOE but is expected to remain relatively stable. Future technical and analytic support for assessments will be provided as requested. ORNL anticipates providing support for analysis of global climate change issues and new analyses in support of the National Acidic Precipitation Assessment Program.

Multiprogram Energy Laboratories Facilities Support—KG

The DOE Multiprogram Energy Laboratories Facilities Support (MEL-FS) program provides funding for general-purpose, line-item construction projects at ORNL. General-purpose facilities support many programs and may include offices, laboratories, and shop buildings that house administrative and Laboratory-wide support functions; utility systems; and roads. Line-item construction projects are those with a total estimated cost of $1.2 million or more.

ORNL has a large backlog of facilities for which a number of corrective construction projects are proposed. Table 9.2 in Sect. 9, "Site and Facilities," provides a more complete description of ORNL's facilities needs and a complete list of proposed line-item construction projects, including those that are being submitted to the MEL-FS program.

Biological and Environmental Research—KP

Goals of the Biological and Environmental Research (KP) Program are to (1) study the interaction of energy-related physical and chemical agents with living organisms and the environment, including their transport, chemical transformations, adverse health effects, and ultimate consequences to humans and the environment; (2) contribute to DOE's Nuclear Medicine Program and other beneficial applications programs; and (3) transfer research findings and technological developments outside ORNL. Research areas in biology include mammalian genetics, molecular genetics, protein engineering, cell biology, carcinogenesis, macromolecular structure, mutagenesis, and risk assessment. Environmental science research covers biogeochemistry, environmental biotechnology, global environmental chemistry, ecosystem studies, geosciences, hydrology, and environmental assessment. Health and safety research encompasses human health analysis, epidemiology, health assessments, radiation and chemical physics, dosimetry, nuclear medicine, and instrumentation development for sensitive detection and monitoring of chemicals. Two unique user facilities contribute to the ORNL Biological and Environmental Research Program: the Oak Ridge National Environmental Research Park and the Bioprocessing Research Facility (BRF). Users of these facilities include staff members from national laboratories and industry and students and faculty members from universities.

The ORNL Biological and Environmental Research program is one of the broadest multidisciplinary life sciences research programs in the nation and covers a diverse range of basic and applied studies. Overall, this program is expected to experience growth in several areas during this planning cycle, including global change research, subsurface sciences, mammalian and molecular genetics, human genome research, and structural biology. A new initiative, which cuts across all elements of the ORNL program, is proposed in computational biosciences.

New Initiative

Computational Biosciences

Recent rapid advances in computer technology and computational sciences have begun to have a major impact on the biological sciences. In the future, the integration of the tools of computational science into both the practice and the communication of the biological sciences will revolutionize our understanding of the biological world in terms of physics and chemistry. Within the next few decades, we may well be able not only to predict the three-dimensional structure of a protein from the DNA sequence of its gene, but also to make reasonable inferences about its function in the organism from which it was isolated. In addition, increasingly sophisticated models of the local, regional, and global environments will allow us to more accurately predict the impact of human actions on the biosphere.

Computational bioscience, an interdisciplinary field focusing on the application of high-performance computing technology to modeling, analyzing, and displaying the underlying behavior and physical principles of biological systems, will have a major impact on these and other areas. This field offers a number of advantages over the use of traditional R&D methods in either the computational or biological fields working independently by

- making use of recent advances in high-performance computing to study biological problems in ways that are complementary to traditional experimental techniques;
- extending the realm of biology to the modeling and simulation of very complex systems whose analysis is beyond the scope of standard experimental techniques;
- permitting more timely solutions, through the use of mathematics, computing, and physical principles, to problems in many areas of biology that are now limited by the inefficiency of even the best experimental investigations; and
- using new tools for analysis and visualization, allowing for insight into complex data that cannot otherwise be obtained.

Computational areas with immediate biological impact include data visualization, pattern recognition, simulation, data communication (networking), databasing, data acquisition (including imaging), virtual reality, artificial intelligence, expert systems, and chaos/fractals. Bioscience areas currently being affected by computational sciences include environmental modeling (climate, ecosystem, population), biological systems analysis and modeling (organismal, biochemical), medicine, anatomy, developmental biology (analysis and imaging), structural biology, protein engineering, molecular dynamics, drug design, genome analysis, and biokinetic modeling.

ORNL and DOE have considerable resources available for application to computational biosciences work:

- the ORNL Center for Computational Sciences, with stated goals that overlap computational biosciences (such as complex data visualization);
- expertise in artificial intelligence, expert systems, and supercomputing;
- core strengths in genetics, genome research, molecular biology, protein engineering, and biotechnology;
- capabilities in X-ray, neutron, and computational macromolecular crystallography;
- recognized expertise in modeling molecular dynamics;
- expertise in biokinetic modeling of radioisotope and chemical behavior in the human body;
- leadership in analyzing landscape pattern and process;
- strong capabilities in global dynamics and critical environmental pathways modeling;

- core strengths in population and ecosystem dynamics;
- multidisciplinary skills in model validation, error and uncertainty analysis; and
- recognized expertise in risk analysis and biostatistics.

Given the local infrastructure, the capabilities of ORNL's scientific staff, and the types of issues under the computational biosciences umbrella, it is apparent that ORNL can play a key role in a number of computational bioscience challenges, some of which are listed here.

- Protein modeling
  - Three-dimensional protein folding simulation.
  - Simulation of kinetics/enzyme reaction mechanisms.
  - Protein cluster analysis—function of newly discovered proteins.
  - Protein engineering—rational protein design.
  - DNA binding protein design—cancer/genetic diseases.
- Genome analysis
  - DNA and RNA sequence analysis, pattern recognition.
  - Modeling of gene function and control.
  - Large-scale genomic organization.
  - Data management structure/inventory/multiple database access.
  - Data reduction (e.g., mapping).
- DNA modeling
  - Three-dimensional modeling of sequence-specific conformation.
  - Interaction of DNA binding proteins and carcinogens.
  - Gene control, site conformational studies, bending, etc.
- Environmental modeling
  - Climate and atmosphere modeling.
  - Population and resource management modeling.
  - Chaotic systems.
  - Contamination modeling.
  - Risk and uncertainty analysis.
  - Regional and large-scale analysis of disturbances and effects.
- Complex data visualization
  - Virtual reality systems for complex biological systems.
  - Climate.
  - Three-dimensional cellular, molecular, and genetic systems.
  - Anatomical and developmental analysis.
- Macromolecular dynamics/structure determination
  - Numerical solution of structures by direct computation from crystallography data.
  - Computational derivation of protein and nucleic acid tertiary structure.
- Biomedical simulations
  - Biokinetic modeling of behavior of radioisotopes and chemicals in humans.
  - Analysis of imaging data to represent organ behavior.

A Director's R&D Fund proposal entitled "Computational Biosciences," funded in FY 1993, establishes an infrastructure for computational biology at ORNL and provides a mechanism for researchers in several divisions to interact productively and develop computational tools and technologies that benefit both ORNL and the research community at large. This project also supports the development of several interdisciplinary technology focus areas. One of these—high-performance computing for protein function, catalysis, and structure prediction and characterization—will have a significant positive impact on the human genome project, structural biology, computational Grand Challenges in rational protein design and drug design, catalysis, and biotechnology. Other technical focus areas (e.g., internal biokinetic dosimetry and anatomical modeling, individual-based population modeling, and medical applications for high-performance computing) will also be pursued.

Funding is being provided by the DOE Office of Health and Environmental Research and is being sought from other sponsors as well. Table 5.7 provides a summary of the anticipated funding.

Table 5.7
Budget projections by fiscal year for the Computational Biosciences initiative
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Operating	2.1	2.2	2.3	2.4	2.5	2.7
Capital	0	0.2	0.3	0.5	0.5	0.3

Analytical Technology—Dosimetry Research and Measurement Science—KP01 • One important task in this area is the development of relationships between radiation exposure and dose by means of modeling the biokinetics of radionuclides within the body and modeling the deposition of ionizing energy within radiosensitive tissues from these radionuclides and from radiation outside the body. Exposure-dose relationships compose the cornerstone of radiation protection and play an important role in the evaluation of medical diagnostic procedures that involve the use of radiopharmaceuticals and X-ray machines.

Development of models describing the biokinetics of radionuclides in persons other than the adult worker has required a substantial departure from the traditional empirical approach of "curve fitting" of observations from a limited number of exposed individuals. As far as is practical, the models now being developed explicitly depict the tissues and physiological processes controlling the movement or retention of radionuclides in the body. This approach allows (1) incorporation of basic physiological information into the model, (2) realistic treatment of decay products formed in the body, (3) meaningful extrapolation of data from laboratory animals to humans, (4) meaningful analogies between an element of interest and physiologically similar elements, and (5) a linkage between excretion of a radioactive element and its movement in body tissues and blood.

Biokinetic models, along with age-specific dosimetric models, developed in the course of this work are featured in Publication 56 of the International Commission on Radiological Protection (ICRP). This publication represents the first international effort to tabulate data on the organ dose per unit intake of individuals of various ages.

The scientific expertise in this program is demonstrated by the extensive participation of ORNL staff on committees and task groups of the National Council on Radiological Protection and Measurements, the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine, and the ICRP. This activity also involves multidisciplinary research aimed at three major areas: (1) cost-effective chemical and biological screening techniques, (2) biological and chemical sensors, and (3) basic technical advances of emerging monitoring technologies.

Passive radiation dosimeters based on alpha track and electret detectors are being applied with considerable success to in situ monitoring of alpha contamination. Targets include both indoor surfaces that are difficult to access and soils. An in situ spectroelectrochemical surface-enhanced Raman sensor, being developed primarily to detect chlorinated aliphatics in groundwater, can detect nicotine and alkaloid metabolites at trace levels. Direct measurements in biological fluids are possible.

We have developed the second-generation fluoroimmunosensor (FIS). Previous FIS devices were developed for "one-shot" measurements; the second-generation FIS devices are designed to be regenerable. By combining FIS technology with a capillary reagent delivery system, we have constructed microscale sensors that can perform a variety of FIS procedures repetitively, remotely, and in situ. These procedures include adding a solid- or liquid-phase antibody, adding secondary reagents (e.g., the labeled "second" antibody when performing sandwich assays), and rinsing to remove unbound impurities. In addition to delivering reagents, the microscale regenerable sensor can sample analytes through a membrane or a porous microcavity, via either diffusion or aspiration. The

latter mode of sampling could be very beneficial in the eventual use of the sensor to measure large molecules.

Another instrument being developed is a portable synchronous luminoscope for low-cost field screening of polychlorinated biphenyls (PCBs). Such a device is being field evaluated by the U.S. Environmental Protection Agency (EPA) for field screening luminescent organic pollutants.

ORNL researchers are internationally recognized for their expertise in neutron dosimetry. International personnel neutron dosimetry intercomparison studies, conducted annually at the Radiation Calibration Laboratory (RADCAL), are a major focus of technology transfer. RADCAL is equipped with radioisotopic sources and an X-ray machine configured to deliver precise doses at specific locations. The major emphasis of the research is on personnel radiation dosimetry, but RADCAL is also involved with nuclear accident dosimetry, radiobiology research, national dosimeter performance test programs, teaching and training activities, and dosimeter intercomparison studies that include beta, gamma, and X-radiation as well as neutrons.

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

Continuing Initiative

Advanced Photonics for Environmental Needs

The next generation of instrumentation for environmental measurements must have a high degree of sensitivity, selectivity, and portability. There is a critical need for these instruments in quantitative studies of waste generation, transport, and remediation, as well as global atmospheric problems such as the world energy balance (greenhouse effect), the ozone depletion problem, and the study of airborne pollutants. For instance, DOE's Atmospheric Radiation Measurement (ARM) Program requires state-of-the-art remote sensing instrumentation. Photonics instrumentation, particularly instrumentation involving novel lasers and newly discovered physical principles, can provide "single-atom sensitivity" and isotopic, atomic, or molecular selectivity. Further, photonics devices are becoming more compact and field-hardened; some (e.g., lasers) can be remotely applied.

The ORNL Health Sciences Research Division is a leader in developing and using laser technology to study fundamental chemical and physical processes. In response to the needs of both environmental scientists and waste cleanup specialists, many new techniques can be focused on applied measurements. As examples, two ongoing instrumentation development programs are directly linked to needs of the ORNL Environmental Sciences Division. One is developing a device to measure ultraviolet B penetration in leaves; the other, a sensitive optical mass spectrometer for measurement of organics in forest canopies. A third proposed device for laser remote sensing of atmospheric species would address the measurement of greenhouse gases.

This initiative is both interdisciplinary (chemistry, physics, and environmental science) and interdivisional in its contribution to solving urgent national problems. This activity is part of a larger photonics initiative being developed by several ORNL research divisions under the auspices of the ORNL Advanced Photonics Working Group. Table 5.8 summarizes budget projections for this initiative.

Table 5.8
Budget projections by fiscal year for the Advanced Photonics for Environmental Needs Initiative
($ in millions—BA)[a]

	1994	1995	1996	1997	1998	1999
Total funding	0.7	0.8	1.0	1.2	1.5	1.8

[a]Funding is being sought from the Office of Energy Research under the Biological and Environmental Research Program (KP).

Continuing Initiative

Biological Imaging and Analysis Center

The recent introduction of electron scanning tunneling microscopes (STMs), atomic force microscopes (AFMs), and photon scanning tunneling microscopes (PSTMs) has brought about a revolution in microscopy. The PSTM, invented at ORNL, can perform high-resolution optical spectroscopy and can carry out chemical mapping with previously unattainable spatial resolution. The STM and AFM have produced topographical mapping on an unprecedented scale. Several hybrid versions of these instruments are on the horizon, and significant breakthroughs in biological imaging and analysis can be expected.

Future research will include development of methodologies for a broad range of biological samples and development of hybrid instruments for chemical mapping. Also targeted for investigation is the use of combined infrared and optical spectroscopy for chemical mapping of biological samples with the PSTM. Application of these microscopes and techniques to structural biology will be emphasized. Table 5.9 summarizes budget projections for this initiative, which supports the Laboratory-wide initiative in biotechnology discussed in Sect. 4, "Summary of Major Initiatives."

Table 5.9
Budget projections by fiscal year for the Biological Imaging and Analysis Center
($ in millions—BA)[a]

	1994	1995	1996	1997	1998	1999
Total funding	0.9	1.0	1.1	1.2	1.2	1.2

[a]Funding is being sought from the Office of Energy Research under the Biological and Environmental Research Program (KP).

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

Environmental Biogeochemistry • The ORNL atmospheric research project concentrates on quantifying several aspects of atmosphere/biosphere exchange that are critical in understanding and predicting the effects of global change. These include wet and dry removal processes and surface emission rates of both natural and pollutant constituents important to tropospheric chemistry and biogeochemical cycling. Major emphasis is placed on determining the interactions of these materials with forest canopies, particularly in complex terrain. New projects include testing and application of throughfall methods for quantifying terrain and canopy controls on deposition in mountain forests and developing and testing methods and models of mercury vapor interactions with land and water surfaces. This work supports DOE tasks in the areas of dry deposition, precipitation scavenging, deposition modeling, landscape scaling, biogenic emissions, and biogeochemical cycles.

Transport studies involve the measurement of naturally occurring radionuclides (^{3}He, ^{7}Be, ^{35}S, and ^{210}Pb), anthropogenic radionuclides (^{137}Cs, ^{239}Pu, and ^{240}Pu), and stable isotopes (^{2}H, ^{3}C, ^{15}N, and ^{18}O) to trace and quantify the dispersal and fate of energy-related materials, as well as fixed carbon, in watershed, estuarine, and ocean-margin systems. The watershed research is focused on identifying groundwater and surface water sources and on quantifying the extent to which atmospherically derived substances such as sulfur and lead biogeochemically interact with drainage-basin soils and vegetation during runoff or snowmelt. The marine research focuses on using biogeochemical tracers to quantify the exchange of materials between land and sea, between continental shelf and slope, and between sediments and water column. Planning and scientific exchange between the Institute of Energy Problems and Chemical Physics and the Institute of Oceanology of the Russian Academy of Sciences and ORNL are aimed at developing a joint research program to investigate biological and biogeochemical effects of increased ultraviolet radiation on marine ecosystems. ORNL-led studies within the program framework include assays for DNA damage in phytoplankton that can be attributed directly to ultraviolet B radiation as well as changes in biogeochemical cycling as traced using radioisotopic tracers and stable isotopes. This program will use ship support from the Russian Academy of Sciences in 1993 and is designed to take advantage of the complementary and unique skills of each organization involved. This research is important (1) for developing predictive capabilities to assess (over large spatial and temporal scales) the net movement and biogeochemical fate of substances associated with energy development and waste disposal activities, (2) for determining the potential effects of these substances on terrestrial and marine ecosystems, and (3) for evaluating rates of transfer and cycling of carbon between various reservoirs that may be influenced by global change.

Radon • Determining the subsurface source of radon-bearing soil gas and its transport and entry into residences is a critical component of environmental radon dynamics. ORNL's Health Sciences Research Division continues to study relevant mechanisms pertaining to houses and geology in the southern Appalachians with funding from DOE's Office of Health and Environmental Research (DOE-OHER). These studies are designed to provide insight into climatic, seasonal, and spatial fluctuations of indoor radon concentrations. They are important to efforts to identify those structures in most need of remedial action, especially the "hottest" 100,000 houses in the United States. Other agencies, including the U.S. Postal Service, are now using our expertise.

Ecosystem Function and Response • Research in ORNL's Environmental Sciences Division for DOE-OHER focuses on a new initiative in ecological research intended to provide fundamental insights into how ecosystems and organisms respond to environmental variations and changes, how these responses are controlled, and how they can be integrated across organizational levels. This new Program for Ecosystem Research (PER) is focused on terrestrial ecosystems and provides the fundamental research to support DOE's implementation of the National Energy Strategy. PER studies will determine the fundamental processes and properties of ecosystems that are critical to the prediction of ecosystem adjustments to perturbations such as global climate change.

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

physiological response of vegetation to stress, nutrient cycling, subsurface hydrologic transport, and effects of nutrient cycling processes in streams. The goals of the Walker Branch Watershed Project directly address the objective of the new PER by providing a mechanistic understanding of the key processes that regulate ecosystem adjustment.

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

National Environmental Research Park • The Oak Ridge National Environmental Research Park is directed to include networking with the other five DOE parks through the ParkNet System. Park goals focus on

- integration and synthesis of existing data across parks, including site characterization data collected as part of the Environmental Restoration Program;
- coordination of activities among parks;
- on-site data management and data organization (including establishment of computer databases of historical data) and coordination with the Oak Ridge Environmental Information Systems DOE waste management activities;
- activities promoting the parks as a coordinated network of cooperating research sites; and
- providing an extant array of experimental sites, the extensive background data, and mechanistic understanding that provide an ecological baseline against which to evaluate ecosystem adjustment to changing environmental conditions.

The Oak Ridge National Environmental Research Park is a component of the Southern Appalachian Man and Biosphere Reserve. Park activity provides special leadership in the region on biodiversity, climate change, and environmental education. The FY 1992 DOE budget for the park was $125,000; this supported an individual to respond to ParkNet inquiries, to sponsor remote imagery workshops, to organize files on existing environmental data, to travel to Research Park meetings, and administratively to manage and monitor activities on the 5008-ha site. As noted in Sect. 7, "Technology Transfer and Science and Mathematics Education," visitors conducted thousands of user days of environmental research, monitoring, and restoration activities in the park during FY 1992. Alternative sources of funding are being developed to actuate a central plan consistent with Research Park objectives. Issues under consideration include climate change, environmental restoration, environmental risk, and sustainable ecosystems. Recent activities that have been conducted at but not funded by the park include administration of wildlife management (deer hunts, turkey and osprey restoration, and pest management), wetlands surveys, herbarium development, and rare plant surveys and management. More process-oriented research funded by DOE, the Electric Power Research Institute (EPRI), and the National Science Foundation (NSF) has addressed nutrient dynamics and ion chemistry studies on the Walker Branch Watershed, evaluations of stream biological diversity, high school honors summer research projects, studies of greenhouse gas effects on tree growth, and workshops on data sharing with the other biosphere components of the Southern Appalachian Man and Biosphere Reserve. Other studies have evaluated forest fragmentation and recovery, forest responses to drought, stream fauna population dynamics, and effects of geomorphology on potential contaminant subsurface transport. Test wells are monitored throughout the site. In addition, various forms of remote imagery have been integrated with ground data using geographic information system (GIS) technology for portions of the park.

Theoretical Ecology • Research efforts on quantification of regional landscape patterns and the processes affecting ecosystems at large spatial scales are being redirected to support the PER. Our theoretical research has explored some basic properties of scaled systems with a view toward taking advantage of the scaled structure in predicting system dynamics. This work is expected to contribute to a future phase of the PER that is devoted to assessment methodology, dealing directly with the issues related to scaling. As a result, new emphasis is being placed on testing and on validation of theory and models through the use of field and remote-sensing data available from the Research Parks and through collaboration with other agencies (e.g., the National Park Service and the Environmental Protection Agency's Environmental Monitoring and Assessment Program).

Continuing Initiative

Subsurface Science Research

We plan to continue our work in hydrology, geochemistry, modeling, and colloid chemistry in support of DOE programs in site-directed subsurface transport of hazardous substances and subsurface microbiology. We will also continue to increase efforts related to heterogeneity of the geological, hydrological, and microbial components of the subsurface environment and will initiate efforts related to the origin or transport of microbes in the deep subsurface. Research in subsurface sciences is directed toward defining, understanding, and predicting the movement of energy-related contaminants in humid regions with highly organic natural waters. In direct response to DOE efforts to address the characterization and eventual cleanup of contaminated facilities, this work is expected to grow significantly because it will represent an essential element in the waste R&D plans (Table 5.10). At present, activities at ORNL consist of laboratory and field studies that are integrated with the development and application of hydrologic and chemical transport models. These studies involve research on the role of colloids and microbial populations in affecting subsurface transformation of byproducts (including mixed wastes), modeling of the spatial heterogeneity of soils, and research on the thermodynamic and kinetic parameters important to contaminant migration at DOE sites. These studies, as well as new initiatives that are responsive to DOE's waste R&D plans, will continue and will provide a unique and sound foundation for understanding subsurface contaminant migration in a humid environment.

Table 5.10
Budget projections by fiscal year for the Subsurface Science Research Initiative
($ in millions—BA)[a]

	1994	1995	1996	1997	1998
Operating expense	6.3	7.0	7.3	7.5	8.0
Capital equipment	0.9	1.0	1.0	1.0	1.0

[a]Funding is being sought under the Biological and Environmental Research Program (KP).

Waste R&D—Basic Science • Some of DOE's contaminated sites can be cleaned up with existing technologies, but in many other cases our level of understanding of the complex systems associated with the remediation of past disposal sites and the transport behavior of contaminants is poorly developed. Foresight in identifying future needs as well as a relatively long-term commitment to research directed at basic science issues related to environmental restoration are required; goals of

this effort are laid out in terms of several decades rather than a few years. Leadership in this area must integrate multidisciplinary science into a focused program of developing the fundamental knowledge required to allow DOE's efforts at restoration to succeed in a cost-effective and environmentally safe fashion. Basic R&D support today will help ensure timely, cost-effective methodologies for tomorrow.

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

- an understanding of the biological, physical, and chemical factors that control the movement and chemical transformations of radioactive, hazardous, and mixed wastes in subsurface and surface water systems;
- the development of methods for the accurate prediction of contaminant movement in the environment (as in the groundwater transport Grand Challenge, part of the High Performance Computing R&D initiative discussed in Sect. 4, "Summary of Major Initiatives"),
- the development of new remediation technologies (physical, chemical, and biological) for environmental restoration;
- implementation of a consistent approach in assessing (1) the impact of remediation on human and environmental health and (2) the health and environmental risks associated with historical, current, and planned disposal operations; and
- use of methodologies in performance assessments and postremediation monitoring.

These broad objectives demand a wide variety of technical disciplines as well as a highly interactive operational structure. For example, significant emphasis must be placed on developing (1) analysis capabilities, including those related to geochemistry and hydrology as well as to risk analysis, and (2) fundamental databases that can support the analytical models. The interactive relationships between wastes of different types and natural processes of varying nature must be studied. Emphasis must be placed on microbial transformations that can be used in remediation and on other biological parameters that can effectively serve as indicators for risk and performance assessment. This work will require enhanced computational capability and the use of artificial intelligence and expert systems as means for aiding restoration decisions. Basic research issues of importance to the waste R&D effort will change as technologies develop and as new problems are encountered.

Health Effects and General Life Sciences—KP03, KP04 • Common themes within these activities are interactions of animals, cells, and molecules with their environments. In the analytical technology area, the physical properties of materials of biological or environmental importance, mechanisms that govern transport and chemical transformations of pollutants, and the details of direct interactions of harmful agents with biological materials are studied with both theoretical and experimental techniques. The efforts encompass interactions at the atomic, molecular, and macroscopic levels in solids, liquids, and gases; on surfaces; and at solid-liquid interfaces. Special emphasis is given to interactions in liquids; efforts include Monte Carlo modeling of the effects of radiation on biological molecules in irradiated matter. Strong emphasis is also placed on the development of techniques that provide advanced instrumentation for characterizing and sensitively detecting a wide range of chemical species and related biomarkers of health effects. Included in this effort are unique applications of laser optical techniques, ultraviolet and soft X-ray spectroscopic techniques, electron-beam microlithography, electron microscopy, scanning tunneling microscopy, mass spectrometry, and picosecond laser techniques. ORNL's program for experimental studies of picosecond processes in liquids, gases, and molecular clusters concentrates on studies of structure and dynamics relevant to energy deposition. Programmatic areas of emphasis in health and general life sciences also include mammalian genetics, protein engineering, and cell biology. ORNL also continues to support OHER's Radon Research Program with the publication of an international newsletter, *Radon Research Notes*, now in its ninth issue. This newsletter describes radon research conducted by DOE, other federal agencies, and the Commission of the European Communities; it is distributed to more than 2200 interested persons.

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

Portions of the mouse genome are analyzed with the objective of building bridges to the human genome and especially of finding functions for human genes that might otherwise be characterized only on the structural level. The developmental pathology of selected mutants is investigated in depth, especially where such mutants provide models for human genetic disorders.

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

The mouse genetics colony, which propagates stocks of hundreds of mutants that have arisen over decades of mutagenesis studies, is an international resource that is being exploited through both outreach and in-house research. Over the past four years alone, mutant stocks have been supplied to over 75 laboratories throughout the world for collaborative or independent investigations. Furthermore, the numerous mutations centered on each of seven specific loci have been characterized into deletion complexes that constitute invaluable resources for intensive regional genome mapping.

Recent accomplishments of the mammalian genetics program include the following:

- A genetic locus encoding a neurotransmitter receptor has been mapped to a mouse chromosomal region associated with a craniofacial anomaly, cleft palate; this suggests that neurotransmitters may play important roles in facial development.
- The mouse agouti gene has been cloned and characterized, thus providing the DNA probes for exploring the biochemical basis of the obesity and non-insulin-dependent diabetes conditions that are associated with the lethal-yellow agouti-locus mutation.
- A gene responsible for pigmentation defects in both mice and humans has been identified. Mutations in this gene are likely to account for type II oculocutaneous albinism, which is the most frequent form of human albinism worldwide.
- Exposure to a priming dose of mutagen (that in itself would be mutagenically ineffective or weak) has been found to alter the structural nature of mutations induced by a subsequent challenging dose in spermatogonial stem cells and to greatly augment the quantity of these mutations.
- Incidences of skeletal anomalies and cataracts among offspring of mice exposed to acute or protracted radiation indicate that current projections of genetic effects of ionizing radiation are not underestimating the hazard.
- A transgenic line of mice bearing the human sickle-cell gene for hemoglobin HB S Antilles has been established on a suitable background so that the line displays characteristics of the disease, including cell sickling *in vivo* and other pathologies.

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

Protein Engineering • Protein engineering (site-directed mutagenesis) represents the use of recombinant DNA technology to systematically alter the structure of proteins by replacement,

addition, or deletion of amino acids in targeted regions. Since its recent inception, protein engineering has emerged as the most powerful tool for probing relationships between structure and function and has opened exciting new vistas for optimizing properties of proteins for medical, industrial, and agricultural applications.

In its breadth and integration of many activities in molecular genetics and biochemistry, ORNL's program in protein engineering is unique among DOE laboratories. Current efforts center on functionally diverse proteins, including ribulose bisphosphate carboxylase/oxygenase (Rubisco), the CO_2-fixing enzyme and a determinant of biomass yield, and epidermal growth factor (EGF), a polypeptide hormone that stimulates cellular growth and differentiation. With respect to Rubisco, two compelling reasons exist for carrying out site-directed mutagenesis: (1) despite the absolute dependence (direct for plant and indirect for animals) of all higher life forms on the enzyme, many mechanistic questions remain unanswered; and (2) if the enzyme's oxygenase activity (detrimental to net CO_2 fixation) could be reduced, major increases in plant productivity might be achieved.

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

Some recent accomplishments illustrate progress made in the protein engineering program:

- The elucidation of the three-dimensional structure of Rubisco by Brändén and colleagues in Sweden validated our approaches to addressing structure-function issues by mutagenesis even in the absence of crystallographic data. These issues include identity of active-site residues, function of active-site residues, active-site location in oligomeric enzymes, and determinants of substrate specificity. Innovative chemical-rescue methods have been applied to questions of substrate specificity.
- Both agonists and antagonists of human EGF have been designed. The agonists may be super growth promoters with clinical application in wound healing; the antagonists offer potential as antitumor agents.
- Altered enzyme specificities have been achieved by combining chemical modification and site-directed mutagenesis.

Cell Biology • Several projects in cell biology support or interface directly with programs already described. The initiation events that convert normal cells to potential cancer cells are an essential stage in carcinogenesis but do not determine whether an overt cancer develops; host factors play a responsible role. Therefore, studies of the factors that influence whether an initiated cell progresses to a tumor or is suppressed in the expression of its cancerous potential are central to the problem of carcinogenesis in general and radiation-induced cancer in particular. Studies continue on the mechanisms of cell-cell interaction and the involvement of such factors as transforming growth factor β (TGF-β) in control of neoplastic growth.

A program for targeting biological materials to specific tissues uses tissue-specific monoclonal antibodies bound to liposomes, which may contain chemotherapeutic agents or genetic material. The goals are drug delivery to affected tissues only, thereby reducing undesirable side effects, or initiating expression of desirable genes in appropriate organs.

Cryopreservation of cells and embryos (with the long-term goal of cryopreservation of multicellular organs) already has a very large and well-demonstrated value as an applied biological technique. Its further development depends on the continuing elucidation of the basic mechanisms in

cell freezing; such studies are in progress. An important recent advance has been the successful cryopreservation of Drosophila embryos, the most complex tissue to be recovered intact.

Continuing Initiative

ORNL Genome Program

The Laboratory is strongly committed to an integrated effort to analyze the human genome. Study of the mouse genome and the development of advanced sequencing and mapping techniques are two thrusts of the ORNL program.

Because of the extensive homologies that exist between mouse and human genomic regions, and because developmental and other experimental studies that are not feasible in humans can be done in mice, the mouse can provide information about the functions of genes that might otherwise be analyzable only by structure. Further, mutations generated in mice provide powerful tools for structure-function correlations.

In accordance with the strong recommendations of an advisory committee, DOE's Office of Health and Environmental Research (DOE-OHER) has funded a multiple-investigator project on mouse-human genome relationships that will proceed as follows:

- using recently added capabilities for long-range DNA mapping, develop a molecular map for an entire mouse chromosome (chromosome 7);
- map human cDNAs in chromosome 7, and elsewhere in the mouse genome, to increase the information on human-mouse homologies;
- by means of our newly added capability in targeted mutagenesis, determine the function of some of the mapped human cDNAs;
- pursue intensive structure-function studies in genomic regions for which deletion complexes have been generated;
- study the feasibility of inducing deletion complexes throughout the genome;
- create molecularly tagged mutations throughout the mouse genome by insertional mutagenesis, using both pronuclear injection and embryonic stem-cell techniques;
- use mutagenesis techniques to create models of human genetic disorders;
- establish a national database for transgenic mouse mutants; and
- employ artificial intelligence and neural network techniques to identify important DNA sequence patterns.

New methods that will increase the rate and accuracy of sequencing and mapping, as well as unique informatics for pattern recognition in new sequence data, are being developed in parallel with the generation and molecular analysis of new germline mutations in the mouse.

Genome mapping and sequencing technologies needed to provide rapid analyses for use in conjunction with analyses of the mammalian genomes fall into several categories:

- For electrophoretic techniques, detection methods that can contribute to rapid DNA sequence analysis include single-molecule luminescence and more general luminescence, phosphorescence, and surface-enhanced Raman techniques.
- A direct DNA analysis method that eliminates the gel electrophoresis step involves chemical construction of an oligonucleotide array on a silica surface to which test DNAs will be hybridized to determine the sequences contained in the DNA. This is termed sequencing by hybridization, and the device is a genosensor chip.
- Another direct method uses mass spectrometers to analyze directly the DNA fragments that are usually subjected to electrophoresis.
- Scanning microprobes, such as scanning tunneling and atomic force, are being used to examine the structure of individual DNA molecules to obtain sequence

information as well as structure and mapping data.

Some of these procedures may be adapted for genome mapping and for analysis of gel blots of DNA. The analysis of mammalian genomes should be expedited as techniques become available.

Unique computer-based sequence analysis methods for identification of biologically important regions in newly sequenced DNA are being developed, drawing on neural network, artificial intelligence, and parallel computational techniques. ORNL has developed and implemented an expert system, the Gene Recognition and Analysis Internet Link (GRAIL), which rapidly and reliably locates gene components such as exons, introns, and gene control elements. Related software is used for the automated assembly of these components to describe whole genes. In addition to GRAIL's use in the mouse genome program, several hundred other laboratories access it electronically for analysis of important human disease genes.

The Human Genome Management Information System at ORNL provides the DOE and National Institutes of Health (NIH) human genome programs with a communication network throughout the international community that is engaged in human genome research. *The Human Genome News* and the *DOE Human Genome Program Report* are published at regular intervals by this activity.

Found throughout the Laboratory and in local industry, facilities that support these main components include

- a 250,000-mouse colony organized for genetic studies;
- a transgenic mouse facility;
- a collection of several hundred stocks of valuable mouse mutations being propagated by breeding or preserved as frozen embryos;
- a program in targeted mutagenesis by embryonic stem-cell technology;
- an NIH-supported database for transgenic mice;
- the ORNL Center for Computational Sciences;
- resonance ionization spectrometry laboratories;
- synthetic chemistry laboratories;
- a laboratory equipped with two DNA synthesizers;
- high-resolution mass spectrometry laboratories;
- analytical chemistry facilities that include high-resolution Fourier transform (FT) mass spectrometry, FT nuclear magnetic resonance, FT infrared, and ultrasensitive laser luminescence capability;
- facilities for sensitive detection of labeled DNA fragments by mass spectrometry; and
- facilities for sensitive detection by enhanced Raman, luminescence, and phosphorescence techniques.

ORNL divisions currently interacting to develop this multifaceted program include Biology, Chemistry, Analytical Chemistry, Health Sciences Research, Instrumentation and Controls, and Engineering Physics and Mathematics. Table 5.11 lists the budget projections for this initiative.

Table 5.11
Budget projections by fiscal year for the ORNL Genome Program
($ in millions—BA)[a]

	1994	1995	1996	1997	1998	1999
Operating expense	6.5	6.8	7.1	7.4	7.7	8.0
Capital equipment	0.3	0.3	0.3	0.4	0.4	0.4

[a]Funding is being sought from the Office of Energy Research under the Biological and Environmental Research Program (KP).

Carbon Dioxide Research—KP05 • In the area of global environmental concerns, ORNL has become a center of expertise in developing global biogeochemical models, implementing data and information systems, fostering the application of high-performance computing to atmospheric general circulation models (GCMs), conducting field and laboratory research on the effects of CO_2 on vegetation, and developing unique instrumentation packages for global applications. These activities are the foundation for the ORNL Center for Global Environmental Studies. This Laboratory-wide program, described in detail below, involves staff members from many ORNL divisions as well as outside collaborators.

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

Carbon Dioxide Information Analysis Center • The Carbon Dioxide Information Analysis Center (CDIAC) compiles, evaluates, and distributes information on CO_2, other greenhouse gases, and long-term climate changes, in support of the CO_2 research program. In the coming years, the center's research activities will reflect the new directions of the program and will include research in all aspects of the global climate change issue.

CDIAC also houses the new World Data Center–A for Atmospheric Trace Gases (WDC-A). The center is a component of the World Data System, established in 1957 by the International Council of Scientific Unions to support the data needs of the geophysical community. The World Data System is a prime method of research data exchange and archiving for the international research community, with a total of 44 data centers worldwide. WDC-A was created in response to the need of the international scientific community for a system to manage critical data related to trace gas cycling and will acquire, assure the quality of, document, archive, and distribute data and information focused on the study of atmospheric trace gases, particularly those that are important to the analysis of issues for global change.

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

Carbon Dioxide Effects • Research at ORNL in support of the DOE Direct Effects Program has shown that the most important effects of increased concentrations of CO_2 in the atmosphere on forest tree species may be the secondary influences on resource use and stress resistance. Following on this principle, future research will investigate the potential for elevated concentrations of atmospheric CO_2 to ameliorate the adverse effects of climate warming on forest tree species. Tree seedlings will be grown in temperature-controlled, open-top chambers in the Oak Ridge National

Environmental Research Park, and physiological and whole-system responses will be measured to explore the mechanisms of plant and ecosystem adjustment. This research will lead to a more realistic assessment of the integrated responses of terrestrial ecosystems to global change. New experiments now under way investigate the role of CO_2-temperature interactions on the growth of forest tree species.

Atmospheric Radiation Measurement • The Atmospheric Radiation Measurement (ARM) Program is a DOE initiative to aggressively monitor atmospheric phenomena that affect heat flux, with the objective of providing an experimental testbed for studying the effects of these phenomena, particularly cloud interactions, on long-wave radiative processes. This information will be used to improve the modeling of atmospheric and radiative processes, with the ultimate goal of improving GCMs. The initial ARM site in Oklahoma began collecting data in 1992, and the data stream has been steadily increasing in volume as instruments have been added. With the addition of whole-sky imaging instruments in July 1993, the data volume is increasing to 1.5 gigabytes per day, and the ultimate volume is expected to be more than 50 terabytes of data per year.

ORNL has been selected as the data center for all data generated by this program and has been receiving data since June 1992; the ARM archive at ORNL has been providing data for reanalysis by the ARM Science Team since December 1992. Staff in the ORNL Environmental Sciences Division are developing the ARM archive facility to provide scientific data management for the project data. This effort includes developing a computerized system to store and manage the tens to hundreds of terabytes of data that will be produced by ARM over the project's 10-year life.

The staff are also developing methods to document the data, provide summaries of the data, and provide user access tools. Documenting and summarizing the ARM data will be particularly critical because the ARM archive will be the primary point of contact for members of the general scientific community seeking data from the project. The ARM archive staff are developing the data management software and acquiring the first increment of a mass storage system for the ARM archive (see Sect. 10, "Information Resource Management"). This system will be able to store approximately 5 terabytes of data.

Continuing Initiative

Center for Global Environmental Studies

The exploration of global environmental issues is of critical importance in determining directions for the future. These issues are complex, interwoven, and global in scale; they include greenhouse gases, climate change, ozone breakdown, deforestation and desertification, resource depletion, and the spread of pollution.

The Center for Global Environmental Studies was established at ORNL in 1989 to provide an interdisciplinary base for exploring these issues. In FY 1992, the center became a Laboratory-wide program, demonstrating ORNL's continuing involvement in and commitment to global environmental issues.

Like the U.S. Global Research Program, the cross-cutting national initiative to which the ORNL center corresponds, the Center for Global Environmental Studies takes a new view of the kinds of research needed in this formidable but exciting field. The ORNL center draws on the Laboratory's unique capabilities in working toward three main goals:

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

Our approach to these global issues includes a large-scale, long-term view; a commitment to collaboration among institutions and among disciplines; and a continual emphasis on realistic policy.

In keeping with the center's large-scale view, the unifying framework of its efforts is global systems analysis: the development of increasingly sophisticated models reflecting the dynamic interactions of subsystems (e.g., global vegetation, human cultures and behaviors) and earth systems (e.g., atmospheric chemistry, ocean composition and circulation) and the links between air, land, and sea. The long-term goal is to develop models that include the effects of demographics, land-use patterns, economics, ecological relationships, and other factors influencing the environment.

Four areas of more specific concentration complement this central focus:

- Measurement science and instrumentation. ORNL has a history of excellence in instrumentation for high-energy physics, health physics, pollution monitoring, nuclear reactor technology, and nuclear and chemical waste. This expertise is now being directed toward atmospheric, terrestrial, and aquatic research. The center benefits from ORNL expertise in laser-based instrumentation (expected to play an increasingly vital role in global change research); mass spectrometry and isotopic analysis; remote sensing and fiber optics, key technologies for climate studies; and automation, miniaturization, and portability. Logical applications of this expertise include laser-based devices to measure trace gases, temperature, and pressure; low-cost, air-dropped packages for reading atmospheric or ocean conditions; and instruments for studying cloud formation and atmospheric properties in support of the Atmospheric Radiation Measurement (ARM) program.
- Data systems. Very large amounts of data are being collected in the course of global environmental research, and much more will be obtained as newer, more sophisticated instruments and monitoring projects emerge. For instance, NASA's Earth Observing System will soon begin transmitting enough data to fill all the books in the Library of Congress—every three weeks. Information systems must handle massive quantities of data and present the data in a user-friendly form. They must also ensure the usability of information over decades, since the importance of some data may not become clear for many years.
- Large-scale environmental studies. Global-scale studies must examine the environment from a longer perspective than traditional ecological research. The ORNL center is developing tools and techniques for understanding how to conduct research on a global scale.
- Policy, energy, and human systems analysis. The effects of human activity and policy (including the effects of technology, energy conversion, land use, population growth, and political and cultural patterns) must be incorporated into global environmental studies. Anthropologists, climatologists, ecologists, economists, geographers, planners, political scientists, and sociologists are needed to examine the decision processes involved in global management of risks and resources. Building on extensive work in progress at ORNL and elsewhere, we are developing a practical approach to the problems of decision making involving many players and complex technical issues. The policy issue work is supported through DOE's Assistant Secretary for Policy, Planning and Program Evaluation and is coordinated by that office. The Carbon Dioxide Research Program (KP05) has supported research and assessments in resource analysis to translate the results from global carbon models and atmospheric circulation models into meaningful results for policy analysis; however, this work was essentially phased out in FY 1992. At present, there is no Work for Others (WFO) funding for policy assessments of global climate change.

Current research areas include the following.

- Development of integrated land-use models. Studies of tropical deforestation in Brazil, sub-Saharan Africa, and Southeast Asia are contributing to the development

of models that integrate the socioeconomic and biophysical aspects of land use. For example, because most of the Brazilian deforestation results from road building and agricultural clearing, the problem and its solution involve nearly every element in the global change picture: land use, politics, environmental systems, and socioeconomic activity. Our work involves close collaboration among experts in geography, ecology, transportation, economics, and other disciplines.

- Refined modeling of the global carbon cycle. Carbon dioxide is the greatest single contributor to the greenhouse effect; therefore, a clearer picture of the sources, sinks, and fluxes of carbon throughout the globe is essential in understanding the greenhouse effect and the climate changes it may bring. Rigorous use of models developed and applied by ORNL's Global Carbon Cycle Research Program has led to the current development of new models that reflect various "feedbacks" within the carbon cycle. These new models are contributing to the development of fully integrated carbon cycle models.
- Information analysis centers. The creation of databases on worldwide climate would allow us to determine whether global warming has actually occurred. Our selection as the ARM user facility and data archive provides a sound basis to begin this research. Development of other areas such as biomass data and human systems data will solidify our role in this arena. Another goal is the development of visualization systems for data-intensive studies. ORNL's Carbon Dioxide Information Analysis Center represents a valuable head start in our data systems initiative. We are also collaborating in an initiative to establish a Center for Human Dimensions and Global Change Data.
- CHAMMP Program. Atmospheric circulation models pose some of the most complex, computer-intensive problems in scientific research today. With new parallel computers, it will be possible to simulate more complex interactions with more detail than previous models and to obtain a broader and more comprehensive view of our earth system.
- International development and global environment. The impacts of both climate change and climate-change policies will fall heavily on developing countries. In this area we are identifying vulnerable regions, determining the effects of existing aid programs on global environmental change, analyzing the impacts of change on current development plans, and finding new opportunities to enhance development while pursuing environmental goals. Energy efficiency, institution building, and technology transfer for developing countries are high priorities for this ORNL activity.
- Improved radiation measurement instruments for the ARM program. Drawing on ORNL's proven expertise, we are developing advanced instrumentation that will provide better data on global radiation and heat fluxes. This will allow development of more accurate atmospheric models.
- Ultraviolet B (UV-B) research agenda. Much ozone depletion is due to various energy technologies, and other adverse effects of pollutants derived from fossil fuel may be amplified by ultraviolet light. A comprehensive analysis of the technical issues associated with UV-B radiation should help to resolve many of the uncertainties dealing with measurement sciences and instrumentation needs and will bring a focus to the issues surrounding UV-B measurements and the effects of potential UV-B increases on biological systems. Through a Critical Issues Workshop, we have begun to develop a comprehensive research agenda for resolving these issues.
- Integrated assessments. We are developing an integrated approach to analyzing the impacts of global environmental change. Existing approaches are generally restricted to projecting short-term changes in resources (e.g., surface water on coastlines) onto current socioeconomic and geographical conditions. The results

of such projections are of very limited use to policy makers. We are working to provide an interdisciplinary analysis, whose starting point will be the real-world problems that policy makers face in a given region and time; the analysis will allow for technological and demographic changes and will indicate how significantly climate change would affect decisions. Our long-term aim is to devise personal computer–based decision support systems for federal, state, and local decision makers.

- A global vegetation model. Building on our current study of the global carbon cycle, we plan to extend the vegetation model to the entire world. The expanded effort (estimated to take 10 to 20 years) will represent a major new contribution to global modeling.
- Development of improved data storage and access techniques. As the ARM program and other data-intensive programs mature, new ways of archiving and accessing information will be needed. The ARM archive will be one of the first data archives to use the new mass storage architecture developed by the National Storage Laboratory at Lawrence Livermore National Laboratory. The ARM archive will develop a user interface to this system that will make data easily accessible to the research and policy community. Our strengths in information analysis and management, combined with ORNL's growing expertise in scientific computing, give us a solid basis for developing better data storage systems and techniques.
- Predictive models for water resources. We are using large-scale assessment techniques and tools developed for assessment of global effects on other resources to develop a major new initiative in water resources directed toward the needs of developing countries. We will develop predictive models that will help decision makers understand freshwater ecology, hydrology, and water resource management in the context of global change.

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

The ORNL Center for Global Environmental Studies is dedicated to an earth system–centered, interdisciplinary approach to scientific research. Human interaction with the environment—through population distribution, land use, technology, energy conversion, and other processes—is viewed as a driving force of global environmental change. The center is uniquely positioned to serve the needs of federal agencies and international efforts and to make a significant contribution to our understanding of the biosphere. Table 5.12 lists budget projections.

Table 5.12
Budget projections by fiscal year for the Center for Global Environmental Studies[a,b]
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Operating expense	20	21	21	21	21	21
Capital equipment	1.5	1.0	0.5	0.5	0.5	0.5

[a]These projections include university subcontracts. About 80% of funding would come from DOE; the remaining 20% would be non-DOE funding.

[b]Funding is being sought from the Biological and Environmental Research Program (KP).

Medical Applications—KP06

Nuclear Medicine • Research in the ORNL Nuclear Medicine Program is focused on the design and development of radiopharmaceuticals for diagnostic and therapeutic applications in nuclear medicine. Key strengths of the program are radiopharmaceutical chemistry, radiochemistry, development of radioisotope processing techniques, and radionuclide generator research.

The High Flux Isotope Reactor (HFIR) represents an important resource for this program, and the development of radionuclide processing technology and generator research are major areas of productive research. A key example is the development of the $^{188}W/^{188}Re$ generator system, which provides carrier-free ^{188}Re as either perrhenate or perrhenic acid for radiolabeling various therapeutic agents. Reactor preparation and generator fabrication have been optimized, and the first large-scale clinical prototypes of the $^{188}W/^{188}Re$ generator are currently being evaluated. Radiolabeled antibodies have been prepared and show tumor specificity in animals. Initial testing in patients with colorectal cancer, in conjunction with the Center for Molecular Medicine and Immunology in Newark, New Jersey, has shown tumor targeting of the radiolabeled antibodies. Optimization of the reactor preparation and processing of a variety of other radioisotopes of biomedical interest is also in progress.

Another area of current research is the development of ^{123}I- and ^{18}F-labeled cerebral receptor antagonists to measure changes in neurotransmission encountered in many neurological diseases. The goal is to measure, by means of external imaging techniques, changes in receptor density or activity that occur in many diseases. Agents under development include new, improved analogs that bind to the cholinergic-muscarinic receptors involved in dementias such as Alzheimer's disease and new analogs that bind to the serotonergic receptors that are involved in mood disorders. In conjunction with the syntheses of these and other agents, new and improved radiolabeling techniques are being developed for radio-iodination of molecules sensitive to the usual methods.

The development of improved agents to evaluate pancreatic insufficiency is also being explored, and a new ^{131}I-labeled triglyceride test agent has been recently developed for the evaluation of gastrointestinal disorders involving pancreatic disease by a simple urine test. Animal testing has demonstrated formation of the expected metabolites, with urinary excretion of significant levels of radioactivity following oral administration. Clinical studies with this agent have also been initiated with collaborators at the Clinic for Nuclear Medicine at the University of Bonn, Germany, and the results of testing in normal volunteers and patients have shown significantly decreased excretion in patients with proven pancreatic disease. This approach thus represents an improved method for the evaluation of pancreatic exocrine function by simple urinalysis after oral administration of the new agent.

Research in this program continues to receive international recognition, and, in addition to these examples, a variety of other agents are being evaluated in both preclinical and clinical collaboration with more than 20 medical cooperative programs at university hospitals and research institutions in the United States and abroad. For example, a cardiac imaging agent developed at ORNL was recently introduced commercially as a new radiopharmaceutical in Japan and is also currently in clinical trials in several other countries, including Belgium and Germany. The medical cooperative programs represent an effective mechanism for further evaluation of agents developed in this program through collaboration with programs featuring special expertise in cardiology, oncology, and other areas. In addition, a variety of invention disclosures, patents, and licenses have been consummated.

Molecular Immunology • The proteins on the surface of cells are tissue-specific and may be altered in kind and amount in the carcinogenic process. We have developed monoclonal antibodies that recognize epitopes on a glycoprotein (thrombomodulin) that is expressed exclusively by lung endothelial cells. This apparently unique glycoprotein provides opportunities for the use of monoclonal antibodies for imaging both the vasculature and tumors. Liposomes can be targeted with these monoclonal antibodies, with the possibility of targeting chemotherapeutic agents. Potential

applications will be explored in the light of results from basic studies of the surface proteins in normal and cancer cells.

Superconducting Super Collider—KS

Research in support of the Superconducting Super Collider is being performed on nuclear collision models and detector physics performance, mechanical engineering, and electrical engineering. (See "Continuing Initiative: High-Energy Physics Research Program and the Oak Ridge Detector Center.")

University and Science Education—KT and University and Science Education—Defense-Related—KV

The ORNL-obligated portion of the KT and KV programs supports the administration and conduct of both university-level and precollege mathematics and science education activities. These programs are described in Sect. 7, "Technology Transfer and Science and Mathematics Education." DOE programs designed to encourage college and university faculty and student involvement in DOE missions provided opportunities for more than 500 academic participants at ORNL during FY 1992.

In the area of precollege science education, the KT and KV programs help to support

- ORNL's core precollege program, the Ecological and Physical Sciences Study Center, which offers over 40 study units for classes in kindergarten through 12th grade;
- initiatives with the University of Tennessee at Knoxville to establish the Academy for Teachers of Science and Mathematics and to provide an alternative path for degreed professionals in technical disciplines to prepare for teaching careers;
- administration of DOE's national Teacher Research Associates Program, which provides summer appointments at ORNL for more than 50 secondary teachers each year;
- a regional mathematics and science camp to encourage young women of middle-school age to pursue further studies in these fields; and
- the DOE High School Honors Workshop in Environmental Sciences and the Appalachian Regional Commission Summer Science Honors Academy for student-teacher teams.

Continuing Initiative

Educational Technology

The Educational Technology Initiative is a bold plan to revolutionize education in the United States by exploiting computer technology. It encompasses both short-term objectives that use existing technology and long-term objectives that will apply new technologies. Short-term projects are selected on the basis of their potential for establishing a foundation for the long-term objectives as well as for their inherent value as learning tools. Examples include

- the Oak Ridge Educational Network (OREN), funded by DOE to develop and demonstrate a model for Internet connectivity for teachers and students in kindergarten through high school, along with software development and analysis to enable teachers and students to access and use the Internet more effectively and at low cost;
- the on-line Smithsonian, a partnership for exploring methods of storing and accessing information on one or two broad topics such as native American history or dinosaurs;
- Demonstration Virtual Reality Teaching Units, portable means for experiencing geography and history; and

- regional workshops, involving teachers and school administrators in the development of these products for school systems.

Budget projections are presented in Table 5.13.

While the long-term objectives will require extensive R&D on hardware, software, and learning paradigms, several ideas are on the drawing board. Examples include

- the Information Store (providing access to computer-based resources);
- furnishing virtual reality capability to precollege classrooms; and
- a holographic animation as a teacher's assistant or mentor.

The Educational Technology Initiative will be developed, implemented, and financed through a consortium headed by ORNL that includes the University of Tennessee at Knoxville (UTK), Vanderbilt University, Tennessee State University (TSU), the Tennessee Department of Education, the Tennessee Valley Authority (TVA), and several industrial partners. A steering committee selected from these organizations will provide management oversight. The work will be performed by several entities:

- The Center for Educational Technology Innovation. This center will be housed with the ORNL Center for Computational Sciences and will share its facilities and resources. Support staff will be drawn from ORNL, other parts of Energy Systems, and other partners in the initiative. An early task will the installation of prototypic high-performance computers and a very high speed network for evaluating virtual reality traffic, interactive video, and database traffic to schools selected as initial program targets.
- The Education Technology Institute (ETI). Coordinated by the ORNL Office of Science Education and External Relations (SEER), ETI will be a joint venture initially involving UTK, Vanderbilt, and TSU to explore the best ways of using this technology to promote learning. It will focus on curriculum development, training to use the technology, research on learning and presentation methods using advanced technology, and the development and staffing of regional training programs for deploying educational technology.
- The Classroom Experimental Projects Office. This office, coordinated by SEER, will work with school systems through the state Department of Education to provide training materials, release time for training, and in-service institutes focusing on using the technology and curricula in the classroom. It will be responsible for selecting target and control test schools and implementing the test curricula in those institutions. The state Department of Education will provide the major support—assisting with the administrative and logistical details of using the new materials in classrooms.
- TVA and the private sector. Experienced in planning, demonstrating, and evaluating educational technologies, TVA will provide technical assistance in hardware, software, school system, and statewide interfacing. Several telecommunications and computer companies have also expressed interest in providing financial and research assistance.

Targeted at kindergarten through grade 8, this initiative is designed to serve as a catalyst for stimulating change in schools nationwide. It combines high-performance computers, high-speed networks, and high-technology advances such as virtual reality and draws strength from a partnership involving government, industry, and higher education. Perhaps most important, it emphasizes learning through direct, interactive experience.

In order to meet national goals for education, the technology of the Information Age must be extended from the nation's offices and factories into the classroom. If we seize the initiative now, the infrastructure will be in place to take full advantage of next-generation technologies as they emerge.

Table 5.13
Budget projections by fiscal year for the Educational Technology Initiative[a]
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Operating expense	5.0	6.0	7.0	7.2	7.4	7.5
Capital equipment[b]	4.0	4.0	3.0	2.0	2.0	2.0

[a]Funding is being sought from the Office of Energy Research under the University and Science Education Program (KT).

[b]Corporate partner capital donations could substantially reduce the capital requirements. These projections include a conservative estimate of the amount required to provide networked individual virtual reality experience in the kindergarten through grade 12 classrooms for this prototype.

Laboratory Technology Transfer—KU

The Laboratory Technology Transfer (KU) program has been established to help bridge the gap between R&D and commercialization. This program supports DOE's portion of cooperative R&D agreements (CRADAs), which provide a range of mechanisms for joint R&D efforts between the national laboratories and industry. CRADAs are discussed in the appropriate programmatic areas in this section; an overview is provided in Sect. 7, "Technology Transfer and Science and Mathematics Education."

Office of Nuclear Energy

The Office of Nuclear Energy (DOE-NE) is the major sponsor of applied nuclear research at ORNL. Programs funded through this office are multidisciplinary and include nuclear reactor development, both civilian and naval; space nuclear power; and isotope production and distribution. Funding levels are given in Table 5.14.

Table 5.14
Office of Nuclear Energy major program summary by fiscal year
($ in millions—BA)[a]

Budget and reporting code	Major program	1992	1993	1994	1995
AF	Nuclear Energy R&D	23.1	21.0	15.0	15.0
AJ	Naval Reactors	0.1	0.1	0.1	0.1
CD	Uranium Enrichment	0.5	1.0	1.0	1.0
ST	Isotopes	7.6	10.0	10.0	10.4
Total		31.3	32.1	26.1	26.5
Percentage of total Laboratory funding		5.3	4.9	3.4	2.6

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

Nuclear Energy R&D—AF

Commercial Reactor Programs • The Light Water Reactor/Liquid Metal Reactor Program has comprised approximately 90 small tasks. Key technology development tasks have included development of robotics technology for reactor maintenance and surveillance, advanced controls, and fuel cycle technology to support the DOE-NE Integral Fast Reactor program. A key addition to the advanced controls program during the past year was the development of a cooperative program with the Electric Power Research Institute.

The Modular High-Temperature Gas-Cooled Reactor (MHTGR) Program has been discussed extensively in past ORNL institutional plans. For the past five years, the commercial program has been linked to the MHTGR program in the Office of New Production Reactors (DOE-NP). The agreement between DOE-NP and DOE-NE called for DOE-NP to support design and most of the technology development. Further, operation of the first NP-MHTGR module was to accomplish the technology demonstration to support Nuclear Regulatory Commission licensing of the commercial MHTGR.

A decision by DOE-NP to postpone a technology selection until 1995 was announced in September 1992, and the program was subsequently closed out, with a closeout budget negotiated for FY 1993 to complete experiments in progress. There will be no funding for the New Production Reactor (NPR) program or the commercial MHTGR program in FY 1994.

The gas turbine MHTGR (MHTGR-GT) was first presented as an initiative at ORNL in 1991. During the past year, design comparisons and cost analyses have provided compelling reasons to substitute this application of MHTGR technology for the steam cycle program funded by DOE-NE. The national MHTGR program has formally changed to the gas turbine option. Cancellation of the NPR program casts uncertainty on the future of MHTGR-GT development.

Space Nuclear Power • ORNL's involvement in space nuclear power has centered on the radioisotope thermoelectric generator (RTG) program and the SP-100 program, both extensively discussed in previous ORNL institutional plans. Energy Systems' production role in the RTG program, supporting NASA's Cassini mission, will be completed in March 1994. Some technology development tasks will continue beyond this date. Although several missions, including a Pluto fly-by, are on NASA's planning horizon, NASA has made no commitment to follow-on missions requiring production of more ^{238}Pu-fueled RTGs. The national SP-100 program is being closed out in FY 1993.

Continuing Initiative

Center for Excellence in Research Reactors

See Office of Energy Research Programs.

Continuing Initiative

Retention of the Pool Critical Assembly

See Office of Energy Research Programs.

Continuing Initiative

Actinide Recycle

DOE has directed the focus of its reactor programs toward actinide management. If actinides with long half-lives can be removed from spent light-water reactor fuel and recycled in a fast reactor, the burden on the spent-fuel repository will be reduced. Further, management of the residual short half-life fission products will require a shorter period of institutional care. ORNL has broad experience in many areas to offer to the DOE actinide recycle program; these include

- fuel cycle analysis,
- equipment design,
- reprocessing flowsheet development and evaluation,
- waste form testing and evaluation,
- robotics,
- National Environmental Policy Act (NEPA) analysis, and
- proliferation analysis.

Table 5.15 outlines the projected budget for the Actinide Recycle initiative.

Table 5.15
Budget projections by fiscal year for Actinide Recycle Initiative[a]
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Total funding	1.5	1.5	1.5	1.5	1.5	1.5

[a]Funding is being sought from the Office of Nuclear Energy under the Nuclear Energy Research and Development Program (AF).

Naval Reactors—AJ

Radiation Shielding Information Center • DOE-NE provides some funding for the Radiation Shielding Information Center, which provides specialized information, computational tools, and a suitable cross-section database to DOE-NE programs by serving as a focal point in the community for technology exchange and making available the latest developments in computing and other technology, data libraries, and bibliographic information. The Radiation Shielding Information Center is described below under "Assistant Secretary for Defense Programs."

Isotope Production and Distribution Program—ST

The mission of the Isotope Production and Distribution Program at ORNL is to supply enriched stable isotopes, selected radioisotopes, and related technical services for research, medical, and industrial applications. This continues to be a significant and highly valued program that uses the unique capabilities and facilities located at ORNL. Radioisotopes for many uses, including medical research, are produced in the High Flux Isotope Reactor; enriched stable isotopes can be produced in the Calutron facility (now on standby). The program mission also includes the development and evaluation of methods for isotope production and separation. Specialized technical services such as preparation of high-purity isotopes and unique chemical and physical forms are also performed. The program has operated since 1990 under a "revolving fund" arrangement, with the expectation that the program would be self-supporting. Competition in the marketplace, the lack of capital funds for

expanding and improving program operation, and rising production costs over which the program has no control have placed the Isotope Production and Distribution Program in jeopardy.

In August 1992, the U.S. House of Representatives Committee on Government Operations, Subcommittee on Environment, Energy, and Natural Resources requested that the Secretary of Energy conduct a review of the Isotope Production and Distribution Program, in consultation with isotope users and appropriate federal agencies, to examine new mechanisms for funding and organization of the Department's isotope program, including involvement of the private sector in joint public-private partnerships, and the future role of the federal government in the supply of isotopes. As a result of this request, DOE contracted with the Arthur Andersen Company to perform a management study of the Isotope Production and Distribution Program.

The Arthur Andersen study, completed in March 1993, specified four essential conditions for program success: (1) access to reliable operating and production facilities; (2) reasonable and predictable operating costs at these facilities, which include only direct costs of production and distribution and incremental overhead costs; (3) reduction in unprofitable capacity; and (4) separate funding for research-oriented isotopes. The study concluded that "Under present operating conditions, organizational framework, and production policies (relating to the full spectrum of isotopes—profitable and unprofitable), financial success appears problematic at best. A number of alternative approaches can be taken. If the isotope products and services are deemed to be of sufficient national value to be produced by DOE with taxpayer support, annual DOE funding combined with such income as can be generated from the sale of products with commercial applications could support continued availability of isotopes for medical, industrial, and research applications."

Assistant Secretary for Defense Programs

Programs sponsored by the Assistant Secretary for Defense Programs (DOE-DP) include Weapons Activities, Nuclear Safeguards and Security, and Materials Production. Funding levels are summarized in Table 5.16.

Table 5.16
Assistant Secretary for Defense Programs major program summary by fiscal year
($ in millions—BA)[a]

Budget and reporting code	Major program	1992	1993	1994	1995
GB	Weapons Activities	0.4	0.2	0.2	0.3
GB	Technology Transfer Initiative[b]	2.3	6.8	10.0	12.5
GD	Nuclear Safeguards and Security	0.4	0.3	0.3	0.3
GE	Materials Production	9.9	13.7	14.5	14.5
Total		13.0	21.0	25.0	27.6
Percentage of total Laboratory funding		2.2	3.2	3.2	2.8

[a]Includes operating BA, capital equipment, and construction if any.
[b]Approximate amount spent at ORNL; funding for this initiative is shared by ORNL and Y-12.

Weapons Activities—GB

Funding in the Weapons Activities (GB) Program supports the Radiation Shielding Information Center (RSIC) and the Technology Transfer Initiative.

Radiation Shielding Information Center • Established at ORNL in 1962, RSIC follows guidelines suggested by the Weinberg Panel of the President's Science Advisory Committee, which

recognized the role that information analysis centers could serve in meeting the technical information needs of modern society in the face of the "information explosion." The center provides in-depth coverage of the radiation transport field and serves the needs of a variety of disciplines on an international basis. RSIC staff members collect, organize, evaluate, and disseminate technical information about shielding and protection from the radiation associated with fission and fusion reactors, weapons, outer space, accelerators, medical facilities, and nuclear waste management. The center continues to be a leader in recognizing the role of computer codes and computer-readable data in technical disciplines and in treating them as valid technical information. As a result, the RSIC collections are a valuable resource of radiation transport computing technology. Staff members are on call to answer queries about radiation transport problems and to recommend solutions that draw on the technical resources available from the center. RSIC has funding from the Nuclear Regulatory Commission and the Defense Nuclear Agency and from several other DOE programs.

Technology Transfer Initiative • A new series of projects was initiated in late FY 1992 in support of the DOE-DP Technology Transfer Initiative. The objective of this initiative is to conduct R&D that will benefit both DOE-DP and the private sector. The new projects, which are carried out in collaboration with the manufacturing personnel at the Oak Ridge Y-12 Plant, bring together a unique combination of people in the DOE complex. The Y-12 manufacturing staff represents DOE's manufacturing and assembly capability (with the exception of electronics). For more than 30 years, this organization has succeeded in taking principles, derived from theory and research, to practice. The combination of this capability with the proximity and resources of ORNL presents a unique opportunity to improve the competitiveness of U.S. industry through a variety of forms of technology transfer, with emphasis on CRADAs. The work being carried out under these agreements is characterized by the words "practical" and "applications-oriented," with the aim of producing technology that can be commercialized in a few years. CRADA project teams are made up of staff from ORNL and Y-12 in roughly equal numbers, with leadership provided by the organization with the critical elements for the technology development and transfer process. At present, ORNL has the lead on eight projects and is supporting five more. The existing projects are

- Metallization for 0.1-μ Range Integrated Circuits,
- Lightweight Materials for Automotive Applications,
- High-Performance Thermoelectric Materials,
- Comprehensive Weld Process Model,
- Atomistic Simulation of Materials: A Neural Network Approach,
- Precision Machining and Inspection of Structural Ceramic Work Pieces,
- Cost-Effective Ceramic Engine Components,
- Machining and Inspection of Ceramic Components,
- Optimization of Jig Grinding Operations,
- Hydroforming Design and Process Advisor,
- Parametric Electric Machine Study,
- Turbine-Generator Set Development and Power Generation, and
- NO_X Programs—Sensors and Systems for Engine Management.

Another 16 CRADAs have been approved by DOE-DP, and more are being developed.

The total DOE funding for the approved CRADAs is $13.5 million, which is matched in kind by an equal or larger amount of private sector funding from one or more industrial partners. This funding level is expected to increase to over $20 million by 1994 and at least $25 million by 1995. A management plan instituted at the start of FY 1993 covers the Energy Systems organizations and provides a mechanism for regularly assessing the progress of the work done by ORNL, Y-12, and the industrial partners.

The benefits of the DOE-DP Technology Transfer Initiative extend beyond DOE, which benefits from the development of technology that will reduce manufacturing cost and/or improve the quality of products needed for the defense of our country, to industry, which becomes more competitive and obtains new products and processes for the marketplace. Finally, this program is

useful to the ultimate customer of the Laboratory, the taxpayers of the United States, through its creation of new and exciting opportunities and jobs.

Nuclear Safeguards and Security—GD

Detection of High Explosives by Tandem Mass Spectrometry—GD06 01 • High-sensitivity/high-specificity detection of the vapors of high explosives is being approached by means of a combination of atmospheric sampling glow discharge ionization and tandem mass spectrometry. The quadrupole ion trap is being developed as the tandem mass spectrometer. This technology can detect explosives vapors at concentrations as low as a few parts per trillion with essentially no false alarms. Efforts over the next five years will focus on improving the glow discharge source; developing new techniques for ion injection; engineering to ruggedize and automate the detector; and coupling with sampling/preconcentration systems to address the screening of personnel and of items such as packages and vehicles.

Materials Production—GE

The materials production program includes the Mark 42 Processing Program and the ^{252}Cf Industrial Sales/Loan Program, which are cosponsored by DOE-ER and discussed earlier in this section (see "Chemical Sciences—KC03"), and the ^{233}U Storage and Distribution Program.

Shielded, safeguarded storage and some distribution of ^{233}U continue in the Radiochemical Development Facility (Building 3019) at ORNL. Equipment for processing ^{233}U has been in standby since 1989. Plans are being developed to improve the condition of the aging facility to ensure safe, long-term storage and distribution of ^{233}U.

Assistant Secretary for Energy Efficiency and Renewable Energy

ORNL works with industry on a wide range of programs for the Assistant Secretary for Energy Efficiency and Renewable Energy (DOE-EE). The Laboratory's goal is to assist in the cost-effective introduction of new technologies to increase energy efficiency and renewable energy use. Success in achieving this goal will contribute to industrial competitiveness, energy security, and a cleaner environment.

CRADAs have markedly increased our ability to work with industry. By the end of FY 1992 there were 23 active CRADAs in the ORNL Energy Efficiency and Renewable Energy Program; 11 more were under negotiation. Agreements arranged by the High-Temperature Superconductivity Technology Center for Electric Power Applications accounted for 15 active cooperative projects with industry, with 7 more in negotiation. Several segments of industry are expressing increased interest in working with the DOE laboratories to develop advanced technologies.

ORNL funding from DOE-EE has increased steadily in recent years, and this trend is expected to continue, as shown in Table 5.17. New or expanded programs in advanced materials development are proposed for the Office of Transportation Technologies (program EE), the Office of Industrial Technologies (program ED), and the Office of Utility Technologies (program AK). An increase in biofuels feedstock development is proposed, to accelerate the wide-scale introduction of this promising renewable resource. Increased funding may be available in other DOE-EE programs in order to support program objectives.

Table 5.17
Assistant Secretary for Energy Efficiency and Renewable Energy major program summary by fiscal year
($ in millions—BA)[a]

Budget and reporting code	Major program	1992	1993	1994	1995
AK	Electric Energy Systems	9.7	11.9	20.9	26.8
AL	Energy Storage Systems	0.8	0.0	0.0	0.0
AM	Geothermal Energy	0.1	1.1	0.7	0.1
CE	Hydropower	0.2	0.4	0.5	0.5
EB	Solar Energy	4.6	4.2	5.7	8.2
EC	Buildings Sector	9.6	11.5	15.6	16.9
ED	Industrial Sector	8.2	9.9	17.8	19.4
EE	Transportation	24.6	28.5	48.2	69.5
EF	Technical and Financial Assistance	2.5	2.1	3.8	3.8
EK	Utility Sector	1.2	0.9	1.3	1.4
Total		61.5	70.5	114.5	146.6
Percentage of total Laboratory funding		10.5	10.8	14.8	14.6

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

Electric Energy Systems—AK

ORNL provides field management of three programs for the Office of Energy Management: Superconducting Technology for Electric Energy Systems, Power Transmission and Distribution

Technologies, and Electric and Magnetic Field Effects. ORNL also provides assistance to DOE in engineering and analytical studies for planning and decision making. Funding levels for these programs are expected to increase.

The goal of the superconducting technology program is joint development with industry of the technology base needed for commercial development of electric power applications of high-temperature superconductivity. The three major elements of the program are conductor development, applications development, and applications support. Technology Center cooperative agreements are the principal mechanism used to facilitate interactions with industry. In collaboration with the Defense Nuclear Agency, a survey of potential industry/utility applications of superconducting magnetic energy storage is being conducted.

In Power Transmission and Distribution Technologies, ORNL is working with the Electric Power Research Institute (EPRI) and other interested parties to improve capacity, flexibility, and efficiency while maintaining high reliability. The program includes development of real-time control and operation to allow power systems to be operated closer to capacity limits; high-capacity options such as high-voltage, direct-current transmission; and technologies designed to improve power quality and safety. Major milestones for FY 1994 include two reports on requirements for integrating renewable generation into the power supply system.

ORNL will assist in developing and implementing a DOE plan for electric and magnetic fields engineering research. The plan focuses on exposure assessment, field management, dosimetry, geophysical modeling, instrumentation, and field characterization.

Energy Storage Systems—AL

For 12 years, ORNL has conducted a program to develop thermal energy storage technologies for industries and buildings. These technologies are used to store energy in the form of sensible or

latent heat and to release this heat as needed for heating or cooling. The current program consists of four cost-shared subcontracted research projects to develop systems for storing heat in wallboard, water heaters, off-peak refrigeration, and high-temperature industrial processes. The program is to be closed out in FY 1993.

Geothermal Systems—AM

ORNL provides technical and analytical support to the DOE Geothermal Division and the Oak Ridge Operations Office for the preparation of an Environmental Impact Statement (EIS) for the Hawaii Geothermal Project. ORNL has prepared a draft Advance Notice of Intent, draft Action Description Memorandum, draft Notice of Intent, and draft EIS Implementation Plan. Remaining work consists of finalizing the Implementation Plan and preparation of the preliminary draft, draft, preliminary final, and final EIS. The project will be completed in FY 1995. ORNL is also conducting a continuing study for the DOE Idaho Operations Office on chemical reactions in geothermal systems.

Hydropower—CE

Research and other technical assistance is provided to DOE Headquarters (DOE-HQ) and the DOE Idaho Operations Office on environmental aspects of the Hydroelectric Systems Program. The second and third volumes of the Environmental Mitigation Study, covering fish passage and dissolved oxygen, were completed in FY 1993. Volume 4, Instream Flows, will be prepared during FY 1994 and FY 1995. Hydropower funding is expected to continue at about the present level.

Solar Energy—EB

Biomass-based technologies can provide renewable sources of liquid transportation fuels, electricity, and chemicals. While most biomass energy now used in the United States comes from wood wastes, resource assessments indicate that significant increases in biomass energy use must come from energy crops. ORNL's Biofuels Feedstock Development Program (BFDP) is DOE's national R&D program on terrestrial energy crops. The BFDP is a mission-oriented research program that supports DOE's research on biomass conversion systems. Its overall goal is to develop environmentally acceptable crops and cropping systems for producing large quantities of low-cost, high-quality biomass feedstocks.

ORNL has provided field management, research, and analysis for the BFDP since 1980. The program's five areas are model wood energy species, model herbaceous energy species, environmental research and analysis, economic analysis and integration, and data and information management. Much of the research in the program, particularly in the first two areas, is performed by cooperators at universities and U.S. Department of Agriculture (USDA) research facilities. The program has included 25 to 35 such cooperators at any given time. ORNL's research efforts have emphasized basic genetics, physiology, and biotechnology projects that support the development of woody and herbaceous crops; resource assessments and economic analyses; and environmental research and analysis.

Efforts in the BFDP are closely coordinated with DOE's biofuels conversion research at the National Renewable Energy Laboratory (NREL). Linkages between feedstock characteristics and conversion technologies are specifically considered in species selection and development. As conversion research succeeds in moving biofuels toward commercial acceptance, interactions between ORNL and NREL will continue to evolve. During the planning period, ORNL will provide technical support on feedstock production for feasibility and scale-up studies planned by DOE's biomass conversion programs.

The BFDP also works with other government and private organizations. Recent activities have included cooperative assessments and work for others (WFO) projects with the U.S. Environmental Protection Agency, EPRI, the Tennessee Valley Authority (TVA), USDA, the U.S. Agency for International Development, and the National Audubon Society.

One project to be completed during the planning period is an assessment of cost, supply, and environmental impacts for energy crops across the TVA region. This project receives WFO funding from TVA and includes work by the University of Tennessee (UT). It is part of a TVA assessment that will project the economics of generating electricity from biomass in a region extending from the Appalachian Mountains to the Mississippi River Valley. The cooperation of ORNL, UT, and TVA is enabling the project to consider energy crops, wood wastes, and logging residues together in a regional cost analysis for the first time, making the project unique in scope and scale. Participation in other such cooperative environmental and economic assessments of biomass energy systems is anticipated during the planning period.

BFDP research during the planning period is expected to make steady progress toward the ultimate goal of economical and environmentally sound energy crops and cropping systems. Increasing emphasis will be placed on environmental studies and resource and economic assessments associated with feasibility studies for scaling up conversion systems. Cooperation with forest products industries on woody crop development is expected to increase, as is international cooperation on biomass energy R&D. Cooperative, cosponsored, and WFO projects will be pursued in all program areas.

Specific milestones for the planning period include the initiation of a poplar breeding project in the Southeast, analysis of results from national-level energy crop supply modeling, and completion of the TVA energy crops cost and environmental assessment by the end of FY 1994. Later milestones include the development of improved tissue culture techniques for switchgrass by FY 1995, the development of early selection criteria for poplars by FY 1996, and the completion of the first phase of switchgrass breeding for the Southeast by FY 1997.

ORNL proposes substantial increases in funding for biofuels feedstock development in future years. We will continue to work with DOE-HQ to exchange information with USDA and to define the roles and responsibilities of DOE and USDA in biomass energy research. We will also work with DOE-HQ to define ORNL's role in feedstock development as DOE-supported research on various biomass conversion technologies reaches development stages that include feasibility assessments and scale-up efforts.

Buildings Sector—EC

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

The BTESM project seeks to identify and develop cost-effective improvements in the design of walls, roofs, foundations, and component materials. Activities in this area have steadily increased in recent years, with significant growth in the number of industrial collaborations.

In recognition of the expanded capabilities available at ORNL for buildings research, the Roof Research Center was recently renamed the Buildings Technology Center (BTC). The BTC, which is housed in a cluster of buildings with over 20,000 ft^2 of space, has a staff of 48 and a budget of $13 million. It offers testing, analysis, and performance and economic modeling in three technical centers:

- The Buildings Envelope Research Center, which includes the Large Scale Climate Simulator for thermal performance durability of roofs, ceilings, and floors; a rotatable guarded hot box donated by Dow Chemical Company for thermal tests of walls, roofs, window systems, and industrial housing panels; and an outdoor test apparatus for roofs, walls, and foundations.

- The Heating and Cooling Technology Center, which has one- and two-cell environmental chambers for heating, cooling, and refrigeration; test rigs for component performance testing, especially heat exchangers and refrigerators; and test rigs for gas-fired systems and components.
- The Existing Buildings Center, with capabilities in building performance assessments and diagnostics.

The Roof Research Center completed a two-year study on the thermal performance of attic insulations under realistic winter conditions using the Large Scale Climate Simulator and the Attic Test Module. This work produced measurements showing that heat loss from natural convection through some low-density loose-fill fiberglass insulations results in as much as a 50% loss of thermal resistance at very cold outdoor temperatures. This work has helped manufacturers develop several new insulation products. In other results of this research, Minnesota became the first state to require that thermal insulation achieve its stated performance at winter design conditions, the American Society for Testing and Materials wrote a new standard practice of determination of thermal performance of loose-fill attic insulation, and the Roof Research Center received the *Popular Science* award for one of the year's ten best achievements in building science and technology. The Center continues to attract numerous collaborative projects, including a CRADA with the Polyisocyanurate Insulation Manufacturers Association, the Society for the Plastic Industries, and the National Roofing Contractors Association. This CRADA helped private industry to begin marketing polyisocyanurate insulation products containing no chlorofluorocarbons (CFCs) in 1993.

Another research area that began in spring 1993 is the low-sloped roof recover and moisture drying project, a partnership with a half-dozen roof material manufacturers. This work will assist building owners in deciding the best methods for extending the life and energy efficiency of new and existing low-sloped roofs. An additional benefit is that federal facilities will be introduced firsthand to new technology options for maintaining existing facilities that save energy; enhance the environment, safety, and health; and reduce construction waste. As many as four ORNL buildings could be used as whole roof demonstrations.

Buildings R&D has the goal of developing new cost-competitive materials and systems that can reduce building energy consumption by 30% by 2010. Specific tasks in building materials include research on advanced insulation concepts, performance tests on existing materials, and retrofit insulation. Each task is facilitated by CRADAs with industry. Particular emphasis is being given to the development of powder-filled evacuated panels that have an R value greater than 50/in. and a lifetime greater than 30 years. The target is to market the panels by 1997. The buildings R&D staff also work with personnel in other ORNL divisions, with several U.S. companies (e.g., Dow Chemical, Trane, and Calspun), and with the ORNL In-House Energy Management Program to upgrade the efficiency of major buildings at the Laboratory.

Existing Buildings Research is a national program to support public- and private-sector efforts to improve the energy efficiency of residential, commercial, government, and industrial buildings. The approach includes (1) development and testing of audit procedures, (2) field tests of retrofit performance, (3) assessment of costs and benefits, and (4) research on advanced technologies and delivery mechanisms. During the next three years, this approach will be pursued with several collaborators, including the U.S. Air Force, the Florida Solar Energy Center, and Texas A&M University.

Building Equipment Research seeks to conserve energy by developing improved equipment for building heating and cooling, water heating, and refrigeration. Major ongoing areas in refrigeration systems include refrigerant mixtures, CFC and hydrochlorofluorocarbon (HCFC) alternatives, and appliance research. The thermally activated heat pump research focuses on promising natural gas technologies. A major multiyear project for the Gas Research Institute is investigating the effects of different absorption heat exchangers and developing a mathematical model for optimizing the performance of these devices. Market introduction of residential natural gas heat pumps in 1995–96 will offer performance that is more than double the efficiency of gas furnaces that meet the 1992 National Appliance Energy Conservation Act standard. Residential gas absorption heat

pumps will also eliminate CFCs and reduce electric utility summer peak loads. Advanced "triple-effect" gas-fired absorption chillers for large commercial buildings should allow U.S. manufacturers to regain a considerable share of a market now dominated by the Japanese.

During FY 1993, development and testing were completed for the Stirling/Rankine heat pump combustor and the linear internal combustion engine heat pump compressor. Collection of field performance data on the Phillips generator–absorber–heat exchanger (GAX) absorption heat pump began during FY 1993. Breadboard tests of high-efficiency components for use with HCFC-134a were also completed in FY 1993, under a CRADA with the Appliance Research Consortium. The objective of this project is to define changes in a 20-ft^3 home refrigerator-freezer that will result in a 50% improvement in efficiency over 1993 DOE minimum efficiency standards.

The purpose of the Buildings Technology Transfer Program is to ensure that private research results are transferred quickly, efficiently, and effectively to private- and public-sector users. ORNL has joined with the DOE regional energy office, with utilities, and with other organizations to establish a task force that focuses on buildings programs in the southeastern United States. A series of four workshops and regional meetings is scheduled annually, and the program also makes use of publications and direct contacts with organizations that serve as intermediaries in reaching the fragmented buildings industry.

ORNL assignments also include work on industrialized housing, infrastructure modernization, and a cooperative project with the National Association of Home Builders on advanced housing.

Moderate increases in budget levels of the buildings programs are expected during the planning period.

Industrial Energy Conservation—ED

ORNL performs applied R&D on five projects for the Advanced Industrial Concepts (AIC) Division. The AIC materials project develops new and improved materials and manufacturing technologies leading to enhanced energy conservation. High-temperature intermetallic and metallic alloys with high ductility, corrosion resistance, and strength are being developed. Metal-bonded composites are being developed for optimal use at temperatures between those of currently available alloys and of ceramics. Coatings and engineered porous materials are being evaluated for various applications. Microwave technology is being pursued because it offers new and exciting potential for materials with unique properties.

A second AIC project is Advanced Bioprocessing Concepts. Fluidized-bed bioreactors are being studied for both three-phase and four-phase operation, including an extraction phase to combine fermentation and separation. Gas-phase bioreactors are also being examined. Predictive models will be developed for ultimate use in scale-up. A preliminary economic evaluation of a system for lactic acid production will be completed in FY 1994. The program also supports an annual Symposium on Biotechnology for Fuels and Chemicals.

Additional AIC projects include the development of microemulsions as low-emission transportation fuels, research on photobiological reactions for enhanced capture of solar energy, and thermal sciences research to investigate concepts such as superconducting thermomagnetic energy conversion. A proposed project for FY 1994 is the use of electric fields to enhance industrial chemical processing.

ORNL is performing R&D on five projects for the Industrial Energy Efficiency Division. The continuous fiber ceramic composite project focuses on the development of processing methods for fabrication of these materials. Two tasks have been assigned to ORNL. Under Assessment and Support, ORNL assisted DOE in developing the program plan and continues to provide technical assistance in project evaluation and industrial interactions. The second task, Supporting Technologies, consists of R&D on generic issues. In this task, numerous milestones have been defined for FY 1994

and FY 1995 in the areas of composite design, materials characterization, test methods, and performance-related phenomena.

A continuing project for the Industrial Energy Efficiency Division is Materials for Advanced Industrial Heat Exchangers. This project provides materials technology support to DOE and its contractors for heat exchanger development projects. Schedules on this project are contingent on progress by DOE contractors. In the chemical heat pump project, the main emphasis is on the development of a program for a high-lift heat pump to provide steam in full compliance with the Clean Air Act. ORNL will complete the draft assessment and program plan in FY 1994.

Two relatively new projects for the Industrial Energy Efficiency Division are the industrial gas turbine project and a project to determine the need for specific R&D on high-efficiency electric motor systems. The industrial gas turbine project is designed to demonstrate ceramic technology in an engine test. ORNL has been assigned responsibility for long-term testing of candidate ceramic materials. During FY 1993 the experimental plan was developed, test facilities were procured and installed, and tensile specimens were procured. The tests will extend fatigue data to times of up to 10,000 h. The electric motor systems project will provide a needs assessment, with extensive industrial input, culminating in a final report and recommendation in FY 1994.

Two projects are under way for the Improved Energy Productivity Division. Alternative Feedstocks for Chemicals and Petroleum Refining Industries is part of a bioprocessing initiative with participation by four national laboratories. ORNL has been responsible for advanced processing concepts during the planning and assessment phase. During FY 1993 the assessment was completed, and an experimental study was initiated on acetic acid production in a bioparticle fluidized bed. The acetic acid R&D is scheduled to be completed in FY 1996. In parallel, development of fluidized-bed saccharification will start in FY 1994. A project to develop in-line sensors for electrolytic magnesium cells, scheduled for completion in FY 1993, is being conducted through a CRADA with Dow Chemical Company. A demonstration project on advanced aluminum forming technology is proposed. This effort will be jointly sponsored by the Office of Industrial Technologies, the Office of Transportation Technologies, and General Motors. The project will consist of the redesign of an automobile door and fabrication using superplastic aluminum components.

A substantial growth in funding for future years will be required to accommodate the present projects and other new initiatives that are under discussion.

Transportation—EE

R&D to improve transportation efficiency and to develop alternative fuels is critically important for meeting Administration goals. ORNL participates in DOE-EE programs on transportation materials, propulsion technology, alternative fuels, transportation data, and policy analysis. Both ORNL and Energy Systems have designated transportation as a continuing initiative, indicating the high priority given to increasing the scope of transportation programs (see Sect. 4, "Summary of Major Initiatives").

The Laboratory's major current project for the DOE Office of Advanced Transportation Materials is Ceramic Technology. The original objective of this project was to develop the technology base required for reliable ceramics for use in advanced heat engines. This goal has been largely met; however, further work is needed to reduce the cost of ceramics. The objectives have thus been expanded to near-term applications in conventional automobile and truck engines. The major portion of this work will be accomplished in the ceramic industry with technology support from government laboratories and universities. The technology will be developed in close coordination with the ongoing DOE and industry engine development programs. An extensive list of milestones has been developed to meet the objectives of the multiyear plan. These include the demonstration of an order-of-magnitude cost reduction in post-sintering manufacturing of a ceramic engine component in FY 1994, completion of casting trials for low-expansion ceramics for exhaust ports in FY 1995, and completion of the development of ceramic life prediction methodology in FY 1995.

Planning for three new materials projects has been started under the heading of Transportation Materials Technology R&D Program Development. Alternative Fuels Compatible Materials R&D focuses on resolving problems in engines and vehicle systems due to new fuels, as well as problems in the fuels infrastructure. A needs assessment and draft multiyear plan have been completed. During FY 1994, work will be initiated on fuel tank materials, mechanisms of friction and wear, materials for biofuels production, and composite compressed natural gas (CNG) cylinders. In later years the project will address adsorbing materials for CNG cylinders, alternative fuel catalysts, and engine component materials. Lightweight Materials development will address materials and process technology to aid in weight reduction in automobiles. The draft program plan was completed in FY 1993, and work was initiated on adhesive bonding of polymer components. Work was also started on advanced forming of aluminum and for a closed metal delivery system. All of these tasks involve CRADAs with industry. In FY 1994 longer-term R&D needs will be addressed, especially areas of process modeling, material performance modeling, recycle technology, and new materials development. Electrochemical propulsion materials development is the third area of an expanded materials program in Advanced Transportation Materials. A draft multiyear plan and needs assessment were completed in FY 1993, and a request for proposals for systems requirements is scheduled for issuance in FY 1994. In FY 1994, Alternative Fuels Compatible Materials and Lightweight Materials will become separate projects.

A continuing project in Advanced Transportation Materials is Tribology, with the goal of understanding and reducing friction and wear of materials such as ceramics and carbon-based materials. Two CRADAs to evaluate the wear of new, in situ–reinforced silicon nitride materials were signed in 1993. During the next year, tests will be completed on carbon-graphite and silicon nitride in lubricated environments to simulate hot engine conditions.

The High Temperature Materials Laboratory (HTML), one of ORNL's user facilities, houses several dedicated laboratories and special equipment to support the Office of Transportation Technologies, other DOE offices, universities, and industry in advanced materials research. A staff of highly qualified researchers is available to work with participants in the user program in planning and conducting their research and interpreting the results. This combination of state-of-the-art instruments and staff expertise has proven to be very effective to research projects by users. At the end of six years of operation, in July 1993, we estimate that there will be 207 agreements, both proprietary and nonproprietary, with 122 industrial institutions and 85 universities.

The HTML Fellowship Program, which started in FY 1992, is directed toward education and technology transfer. This mission is accomplished through use of graduate, postdoctoral, industrial, and university faculty fellowships. The activity emphasizes research conducted by the fellows in the HTML but also includes assignment of HTML research scientists in industrial laboratories. By July 1993, four participants—two industrial, one faculty, and one graduate—had been included in the program.

During FY 1992, the Ceramic Manufacturability Center, a partnership between DOE Defense Programs and DOE-EE using expertise developed at the Y-12 Plant and ORNL, became the seventh dedicated laboratory of the HTML. A new Surface Durability and Performance User Center is planned for initial operational startup in FY 1995.

For the Office of Alternative Fuels, ORNL provides technical support and R&D on the Alternative Fuels Utilization Project. A major current project consists of a CRADA on improved catalysts and emission controls with General Motors, AC Rochester Division. Catalysts for natural gas and alcohol fuels are emphasized, and the R&D includes materials characterization, bench tests, and detailed measurements of catalyst performance on test standards. A multiyear plan update for Alternative Fuels will be completed in FY 1995. A new effort being planned for FY 1995 is bioprocessing research in support of the Alternative Fuels Program.

An Automotive Propulsion Technology project for the Office of Propulsion Systems complements our work on alternative fuels utilization by examining and testing concepts for advanced engines. A second project has the objective of identifying space conditioning systems that

are nonpolluting, cost-effective, and energy-conserving. This project will be completed in FY 1994 with three reports detailing the findings. A new project, Development of a Thin-Film Rechargeable Lithium Battery for Electric Vehicles, has been proposed. The research will focus on manufacturing thin-film cathodes that can sustain the same current densities as bulk materials.

Also for the Office of Propulsion Systems, ORNL conducts research on mobile air conditioners, with the objectives of efficiency improvement, CFC replacement, and development of heat pumps for electric vehicles.

ORNL supports the office of the Deputy Assistant Secretary for Transportation Technologies with analyses of motor vehicle data and energy use. The results are published in a biannual report, the *Transportation Energy Data Book*. We also perform selected studies on energy policy issues as related to fuel economy and clean air considerations.

A substantial increase in funding for transportation programs is expected during the planning period. Increases are likely for ceramic technology, lightweight materials, alternative fuels, and the HTML. Additional new projects on hybrid vehicles and manufacturing science may be initiated.

Technical and Financial Assistance—EF

ORNL provides evaluation and technical support for a number of programs in the Office of Technical and Financial Assistance. The major current effort is the evaluation of the Weatherization Assistance Program. Data on a nationally representative sample of program participants and matched control groups are being collected and analyzed. This evaluation will end early in FY 1994.

Assessments are also under way on two information programs: the Conservation (now Energy Efficiency) and Renewable Energy Inquiry and Referral Service and the National Appropriate Technology Assistance Service. Final reports on these two programs were prepared in FY 1993, and a continuing assessment strategy is being developed. ORNL is conducting an ongoing analysis of the process of innovation in the Technology Commercialization Evaluation Program. ORNL also supplies technical information for the Weatherization Assistance Program and provides technical information and management support to the International Energy Agency Center for Analysis and Dissemination of Demonstrated Energy Technologies and to the Asia Pacific Economic Cooperation Energy Project. These programs are designed to facilitate technology transfer among the nations of the world. Additional studies in these areas will probably be undertaken as current work is completed.

Support for the international programs of the Office of Technical and Financial Assistance is increasing. ORNL is working with DOE and industry groups to implement a new interagency Committee on Energy Efficiency Commerce and Trade (COEECT) as a partner of the Committee on Renewable Energy Commerce and Trade (CORECT). COEECT was established by the Energy Policy Act of 1992 to assist in promoting international energy efficiency. Initial ORNL tasks include development of a program plan and an industry participation strategy. Increased funding for COEECT is expected as the program plan is implemented.

Utility Sector—EK

In Integrated Resource Planning, ORNL activities are organized under four topics: evaluation, analysis, utility planning, and technical assistance Recently completed tasks include analysis of the efficiency of emission trading and evaluation of demand-side management collaboratives. The District Heating, Cooling, and Cogeneration program was completed in FY 1993.

Assistant Secretary for Fossil Energy

ORNL programs for the Assistant Secretary for Fossil Energy (DOE-FE) cover research in coal, petroleum, innovative clean coal technology, and support to the Strategic Petroleum Reserve.

The principal focus of ORNL's fossil energy activities, however, is coal. The coal budget is anticipated to increase in FY 1994, primarily because of additional efforts in materials, chemical processing and bioprocessing of coal, and environment, safety, and health (ES&H) areas. Budget projections are given in Table 5.18.

Table 5.18
Assistant Secretary for Fossil Energy major program summary by fiscal year
($ in millions—BA)[a]

Budget and reporting code	Major program	1992	1993	1994	1995
AA	Coal	6.2	6.1	8.2	10.5
AC	Petroleum	0.1	0.7	2.1	2.0
AN	Energy Technology Center Program Direction	0.0	0.0	0.0	0.0
AW	Fossil Energy Environmental Restoration	0.0	0.0	0.0	0.0
AZ	Innovative Clean Coal Technology	3.0	0.4	0.8	0.6
SA	Strategic Petroleum Reserve	0.1	0.3	0.4	0.4
Total		9.4	7.5	11.5	13.5
Percentage of total Laboratory funding		1.6	1.1	1.5	1.3

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

Coal—AA

Work on coal technologies comprises the major portion of the ORNL Fossil Energy Program budget. Significant programs are under way in materials research, bioprocessing, coal combustion, and ES&H areas. A strong budget position has been maintained in materials research, and bioprocessing and ES&H activities are experiencing growth. Coal combustion remains an important research activity, albeit with somewhat lower funding than other areas of the program.

The ORNL Fossil Energy Program has the technical lead and responsibility for technical management with the DOE Oak Ridge Operations Office (DOE-ORO) for the Fossil Energy Advanced Research and Technology Development Materials Program. In addition to traditional structural materials R&D on ceramic composites and advanced alloys, functional materials (i.e., materials that possess properties important to performance of a specific function, such as solid-state electrolytes and inorganic membranes) have been integrated into the materials program.

Fiber-reinforced ceramic composites with improved strength and toughness are being produced by the forced chemical vapor infiltration and deposition process developed at ORNL. Ceramic composites have a variety of applications in fossil energy systems; these include high-temperature heat exchangers and hot-gas cleanup filters. Current work also emphasizes understanding the nature of the fiber-matrix interface with the aim of improving the mechanical properties of composites. Ceramic membranes for the separation of gases in high-temperature and hostile environments are being developed and tested. The feasibility of microwave-assisted chemical vapor infiltration of ceramic preforms is being explored.

ORNL is developing advanced austenitic alloys for use in fluidized-bed and pulverized coal combustion power plants. The objective of this work is to modify existing alloys so as to provide the strength and corrosion resistance needed in high-temperature, high-pressure, second-generation power plants. Current materials and designs for tubesheets and manifolds for hot-gas filter systems are being

examined; the aim is to recommend a tubesheet material suitable for long-term operation of these systems.

Intermetallic alloys based on iron aluminide are being developed for applications in which superior oxidation and sulfidation resistance and strength are required. Improved room-temperature ductility, resistance to hydrogen embrittlement, and fabricability will continue to be emphasized in the next several years.

Corrosion research at ORNL centers on studies of the formation and breakdown of protective oxide scales, particularly in sulfur-containing atmospheres, and on the effect of environment on corrosion of iron aluminides. An understanding of the properties and characteristics of oxide scales is evolving.

ORNL is committed to transferring the technology developed in the Fossil Energy Materials Program to industry and to others in the fossil energy community. ORNL has three licenses to produce iron aluminides in powder form (Ametek) and wrought form (Hoskins and Harrison). An option license agreement for the Fe_3Al technology has been executed with Castmasters, Inc., to evaluate the technology in two applications. Several CRADAs are under discussion, and a CRADA with the 3M Company has been completed for the transfer to industry of a process for fabricating full-size ceramic composites using technology developed at ORNL.

Coal combustion research includes technical support to DOE's Pittsburgh Energy Technology Center (PETC) for projects in India, directed primarily to the introduction of state-of-the-art coal combustion technologies; a CRADA project with Babcock and Wilcox on the analysis of fluidized-bed combustion data for deterministic chaos; and a project to evaluate the products of mild gasification to determine the potential uses of these products in combustion systems.

In the ES&H area, ORNL provides technical and analytical support to the Morgantown Energy Technology Center by evaluating environmental concerns related to coal research and development projects and by preparing National Environmental Policy Act (NEPA) assessments of the projects. Future work may involve performing field studies to collect environmental data for use in upcoming assessments.

Bioprocessing for coal conversion and utilization represents a growing effort in the ORNL Bioprocessing Research and Development Center. Activities include the conversion of coal to useful liquid and gaseous fuels as well as the removal of heteroatoms and hazardous materials from coal, coal liquids, and gaseous and liquid effluents. Innovative microbial and biochemical pathways for bioprocessing concepts are being investigated for use in these areas, and advanced bioreactor systems that can efficiently and economically carry out such processes are being developed. Over 40% of some types of coal can be converted to liquids by reduction processes that are catalyzed by modified enzymes that can operate in organic solvents. Other biocatalytic systems have been shown to remove much of the organically bound sulfur that contaminates coal-derived liquids. Cooperative research with academic and industrial researchers is being conducted in almost all phases of this bioprocessing effort.

Molecular hydrogen is a valuable chemical feedstock for the liquefaction and gasification of fossil fuels. Virtually all hydrogen used in current processes is itself derived from fossil fuels. Current research is focused on the production of molecular hydrogen via photosynthetic water splitting. Certain unicellular microalgae are capable of sustained simultaneous photoevolution of molecular hydrogen and oxygen. Net thermodynamic conversion efficiencies of light energy into chemical energy of 5 to 10% have been achieved in the linear low-intensity region of the light saturation curve of photosynthesis. The present research will provide baseline information that will be used in the selection of the best algae for the task and in the design of optimum photobiological reactors for use in real-world chemical engineering processes.

Petroleum—AC

Technical and analytical support is provided to DOE for the Oil Research Program. An important component of ORNL's involvement is environmental support in preparing a programmatic NEPA assessment of the program. The goal of the Oil Research Program is to maximize the economic producibility of domestic oil resources by implementing a research, development, and demonstration plan in collaboration with state governments, industry, and academia.

A bioprocessing R&D program is being developed for treating petroleum, petroleum-derived products, and effluent streams. The most significant effort is a cooperative research program that is being developed with several oil companies for the removal of sulfur, nitrogen, and other contaminants from crude petroleum and other refinery streams. This program will involve a CRADA with a major oil company.

A program is also being developed for recovery of hydrogen from petroleum refinery purge gas streams using inorganic membranes. This program includes a CRADA with Media and Process Technology, Inc.

Energy Technology Center Program Direction—AN

Technical assistance is being provided to the PETC in the implementation of collaborative coal projects in India under a cooperative agreement between the U.S. Agency for International Development and the Government of India. We anticipate that this work will continue through FY 1995.

Fossil Energy Environmental Restoration—AW

Technical assistance is being provided to the PETC in satisfying NEPA requirements for the retirement and dismantling of the Advanced Coal Liquefaction Research and Development Facility in Wilsonville, Alabama. We anticipate that this environmental restoration effort will conclude in early FY 1995.

Innovative Clean Coal Technology—AZ

Work on the Clean Coal Technology Program (CCTP) includes support in the areas of environment and materials. The CCTP is jointly funded by DOE and industrial organizations. Four solicitations have been completed by DOE, and a fifth is under way. An important part of ORNL's involvement in the CCTP is environmental technical support to DOE in the preparation of NEPA assessments of site-specific projects. Materials failure analyses (critical to the success of clean coal technologies) continue to be conducted for the PETC. Work related to the CCTP is expected to remain at the present strong level of effort over the next five years.

Strategic Petroleum Reserve—SA

ORNL provides assistance to the Strategic Petroleum Reserve (SPR) Program in the assessment of alternative methods of financing oil acquisition and in the development of models for planning the capacity and management of the SPR. Funding for these support activities is expected to remain level in the next five years.

Assistant Secretary for Environment, Safety, and Health

ORNL work for the Assistant Secretary for Environment, Safety, and Health includes development of environmental policy assessment methodologies and models, applications of these models to analyze proposed and existing environmental legislation and regulations, development of environmental compliance guidance, planning and assessment of technologies for dealing with radiological emergencies, participation in DOE assessments, and training of DOE and contractor staff in compliance with environmental laws and regulations. Table 5.19 presents summary budget information for this program area.

Table 5.19
Assistant Secretary for Environment, Safety, and Health major program summary by fiscal year
($ in millions—BA)[a]

Budget and reporting code	Major program	1992	1993	1994	1995
HA	Environmental Research and Development	7.6	7.1	9.6	10.2
HR	Epidemiologic Activities	0.0	0.0	0.0	0.0
HS	Office of Security Evaluations	0.1	0.1	0.1	0.1
KK	Policy and Management—Nuclear Energy	3.2	3.2	5.1	5.3
NS	Nuclear Safety	0.6	1.7	1.9	1.9
Total		11.5	12.1	16.7	17.5
Percentage of total Laboratory funding		2.0	1.8	2.1	1.7

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

Environmental Safety and Health—HA01

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

Environmental Guidance and Compliance • ORNL will continue to provide extensive technical support to the Office of Environmental Guidance. Long-standing work for this office encompasses a variety of regulatory activities, including the tracking and analysis of regulations and the development and dissemination of regulatory information and guidance. ORNL has provided substantial support for training in environmental laws and regulations, and the development and implementation of training courses in these areas for DOE and its contractors will continue. Future efforts will focus on subjects important to DOE's environmental restoration program, such as Resource Conservation and Recovery Act (RCRA) closures and the Natural Resources Damage Assessment process.

ORNL also provides technical support to the Office of Environmental Guidance in standards and procedures development, calculational model validations, risk assessment, and radiation protection requirements. In the area of procedures development, ORNL is developing a radiological survey procedures manual, which provides detailed specifications for measurement and assessment of radiological environmental pollutants. The manual will serve as the basis for radiological surveys at DOE and contractor facilities. ORNL staff also provide support to DOE's Risk-Based Standards

Working Group, which is developing guidance on health and environmental risk assessments performed at DOE facilities.

NEPA Oversight • ORNL continues to provide technical support to the Office of NEPA Oversight. This includes assistance with the development of guidance for compliance with NEPA, preparation of related background information, review of NEPA documents, and assistance at DOE-HQ. A major initiative related to the DOE rule on NEPA compliance (10 CFR 1021) is assistance with the revision of the Office of NEPA Oversight's *NEPA Compliance Guide*. ORNL is developing audit protocols to assess compliance with NEPA at DOE facilities nationwide.

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

Safety Policy and Standards • ORNL has the capability to conduct large-scale hydrogeological and environmental characterization activities that are essential to addressing the contamination problems on many DOE sites. An increasing interaction with regulatory agencies is creating the need for a uniform, efficient, and well-organized approach to the development and initiation of site-wide characterization studies. ORNL plans to serve as the coordinating center for characterization of selected DOE sites throughout the country, drawing heavily on the experience developed in work done on the Oak Ridge reservation, which is hydrogeologically the most complex of any of the sites. ORNL technical support in site prioritization efforts, environmental audits, and emergency response R&D is available.

Staff from the ORNL ES&H Compliance organization, supported by staff from the ORNL Health Sciences Research Division, coordinated the initial DOE-wide Safety and Health Five-Year Planning Process for the Assistant Secretary for Environment, Safety and Health and continue in coordinating the process refinement and functional implementations.

Neutron Dosimetry • Improved neutron dosimetry is needed at all DOE facilities and in industry. Superheated drop (bubble) technology is one of the most exciting and promising advances in neutron dosimetry in the past two decades. The Dosimetry Applications Research (DOSAR) group has combined the threshold detection features of bubble dosimeters with the traditional broad response of thermoluminescent albedo dosimeters to develop a Combination Area Neutron Spectrometer (CANS) and a Personnel Neutron Dosimeter/Spectrometer (PENDOS). Because the resulting unfolding analysis techniques are simple, this combination rapidly yields both the neutron dose and the neutron energy spectrum. As these instruments are developed and the technology is transferred to industry, they should form the core of a new generation of small, accurate, low-cost neutron personnel dosimeters and spectrometers.

Material developed for use as three-dimensional (3-D) optical random access memory (ORAM) in high-speed computers is of interest to ORNL scientists as the basis for a revolutionary neutron dosimeter. Both DOE and the nuclear industry need an energy-independent neutron dosimeter that is practical to use and can be processed for a reasonable cost. The 3-D ORAM material functions as a neutron detector, changing color at sites that interact with secondary charged particles when the material is exposed to neutrons. Visible lasers can be used to determine both the total amount of color change, which is related to the neutron dose, and the spatial distribution of color centers, which corresponds to the neutron energy. The neutron energy discrimination is expected to be orders of magnitude more sensitive than that of existing personnel dosimetry methods because of the very high neutron interaction and information storage capability of ORAM. This research will result in the only dosimetry method that allows precise neutron dose measurements independent of energy and could result in a replacement for both film and thermoluminescent dosimeters now in use.

Nuclear Accident Dosimetry Performance Test Program • DOE facilities at which the potential for a nuclear criticality accident exists are required to have nuclear accident dosimetry capabilities and to ensure that they will function properly. Annual Nuclear Accident Dosimetry Intercomparison Studies conducted at the Health Physics Research Reactor (HPRR) met training, educational, and performance testing needs until the HPRR was shut down in 1987. Since then, no

such testing or training has occurred. The DOSAR group is attempting to organize a Nuclear Accident Dosimetry Applications Test Program using the fast pulse reactor at the Army Pulse Radiation Facility in Aberdeen, Maryland. The proposed program is essential to provide for proper testing, education, and training throughout DOE.

Continuing Initiative

Center for Risk Management

ORNL's Center for Risk Management (CRM), established in 1991, is an interdisciplinary R&D center that addresses the risks to human health and the environment that are associated with hazardous waste and energy production. The center's main goals are to

- prioritize and solve environmental and health problems,
- promote cost-effective remediation of hazardous waste sites,
- promote innovative methodologies for assessing and reducing risks,
- promote fundamental biological research in risk assessment, and
- promote training and educational initiatives in risk assessment.

The center draws on the diverse capabilities of ORNL to address these health and environmental issues more efficiently than other, smaller institutions. Environmental restoration activities are a primary focus of the center; however, all significant global health and environmental problems fall within the scope of the center's work. Other current interests include the management and reduction of radionuclides and toxic chemicals, acid deposition, and climate change.

ORNL researchers are among the world's leaders in using concepts from risk assessment to achieve a balance between the risks and benefits involved in proposed solutions to local and global health and environmental problems. In the CRM, ORNL's scientific resources and expertise in health and safety, biology, environmental sciences, social sciences, and engineering are applied to evaluating risks and to determining the best methods for reducing them. The CRM also provides training for professionals and offers educational opportunities to the public to promote two-way communication between these groups on the management of environmental and health risks.

These activities support an underlying goal for the CRM: integrating science into decision making. Zero-risk solutions to environmental regulation are clearly impractical. An alternative is to base decisions on balancing risks with benefits. With informed decision making, management can ensure that risks to human health and the environment are addressed in the most efficient and expedient manner possible. In addition to developing risk methodologies and performing risk assessments, we will provide technical assistance to managers who must interpret the findings of risk assessments and make decisions about the best ways to manage risks.

Areas of focus

Researchers from ORNL examine how their fields of science might affect or be affected by specific environmental problems. Examples of activities vigorously pursued by the CRM follow.

- Environmental fate/transport modeling. The CRM focuses on the application of different models to specific sites and issues. Overall modeling activities consider atmospheric, terrestrial, surface water, and groundwater transport of radiological and chemical contaminants. The movement of acidic materials and their impacts on forest ecosystems and forest soils are investigated; environmental transport is modeled in areas ranging from emergency preparedness to the long-term performance of radioactive waste disposal facilities.

- Molecular toxicology and biological monitoring. The CRM is involved in developing biomarkers for exposure to carcinogenic chemicals and molecular assays for identifying chemical promoters. The CRM is also investigating the effect of nongenotoxic carcinogens on tumor suppressor genes. In addition, we have developed a biologically based model of carcinogenesis that incorporates biological data on cell numbers, cell division rates, and probabilities of genetic damage. Using such an approach for interspecies extrapolation reduces uncertainties in risk analysis.
- Risk analysis. The CRM develops and applies new methodologies in human health and environmental risk assessment and characterizes uncertainties in the risk assessment process. Additionally, the CRM evaluates data on the release of hazardous substances into the environment to assess current or future impacts on public health.
- Site characterization. ORNL staff in the Pollutant Assessments Group in Grand Junction, Colorado, and in the Methodology Applications and Development Group in Oak Ridge are characterizing contaminated sites at federal facilities nationwide. Staff members have a broad knowledge of geological, physical, and biological sciences, along with experience in sampling an extensive range of media for pollutants. Detectors and sampling apparatus make it possible to deal with virtually any radiological, chemical, or mixed material that is encountered. Several hundred sites have been investigated during the last 3 years at over 20 facilities in a dozen states for DOE, the Department of Defense, and the Department of the Interior.
- Database development. The CRM is developing more effective database systems that serve as management decision-making support tools. The development of toxicological databases is a primary focus of the CRM, which maintains extensive databases on the toxicological and environmental properties of chemicals commonly found at hazardous waste sites.
- Risk education and communication. The CRM promotes awareness and understanding of human health and environmental risks to various audiences, including school-age children, the general public, and risk professionals. Models in risk education are being prepared for use with middle school and high school students. Technical training workshops are conducted for environmental professionals who are involved in health assessments and environmental remediation of hazardous waste sites.
- Geographical Information Systems (GISs). GISs use computer tools and resources to capture, manipulate, analyze, and display all forms of geographically referenced information. They also provide means for conducting complex spatial processing and analysis of environmental problems at hazardous waste sites.

Specific projects and goals

The following overview of activities reveals the magnitude of the center's interests.

- Prepare the risk assessment portion of the Programmatic Environmental Impact Statement (PEIS) for environmental restoration and waste management activities. The PEIS will help establish a consistent, integrated national approach for managing these activities at DOE's more than 7,000 hazardous waste sites. The human health and ecological risks posed by these waste sites will be estimated in order to evaluate the degree of cleanup required and the cost of reducing risks to levels that will ensure public, worker, and environmental safety.
- Provide forums for technological exchange in support of environmental restoration activities and decision making. The CRM has sponsored three workshops for DOE on risk assessment, land use issues, and groundwater.
- Perform a critical analysis of existing information relating to safety and

regulatory compliance of the molten salt oxidation (MSO) technology as a waste treatment alternative for DOE. Using ORNL scientific resources and expertise, the CRM will conduct analyses using risk assessment methodologies to evaluate health and environmental risk, cost, and socioeconomic impacts of MSO technology.

- Develop and support a DOE Safety and Health Database System for the DOE Safety and Health Five-Year Plan. This plan, a risk-based ranking of all safety and health expenditures throughout DOE, delineates strategies and programs being pursued by DOE to reduce and manage safety and health risks, including the scope, priorities, resource requirement estimates, and schedules for all major safety and health activities.
- Develop a prototype GIS for the Agency for Toxic Substances and Disease Registry (ATSDR). The CRM has sponsored three national meetings on the use of GISs for hazardous waste problems at DOE facilities.
- Coordinate ATSDR public health assessments at DOE facilities. The CRM facilitates communication among DOE headquarters, DOE facilities, and ATSDR with regard to ATSDR public health activities across the DOE complex.
- Conduct performance assessments of several new radioactive and chemical waste disposal facilities at the Savannah River Site and the Nevada Test Site, as a means of estimating the potential transport of contaminants through the environment to human receptors. Environmental transport models that simulate aquifers, the atmosphere, and the food chain are maintained and used.
- Assist the Hazardous Waste Remedial Action Program (HAZWRAP) as technical specialists on risk assessment. The CRM promotes risk-based approaches to evaluating and prioritizing hazardous waste sites within the DOE complex.
- Provide health assessment training for ATSDR. The CRM assists ATSDR in the training of state health officials with regard to determining off-site human health impacts at hazardous waste sites.
- Develop a database and modeling tools for evaluating the feasibility of establishing national consistent soil quality criteria for protection of groundwater.
- Conduct a survey of ecological risk management capabilities and activities at DOE sites.

Table 5.20 gives the budget projections for the CRM.

Table 5.20
Budget projections by fiscal year for the Center for Risk Management
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Total funding	26.0	30.0	30.0	30.0	30.0	30.0

Continuing Initiative

Health Physics Instrumentation Center of Excellence

There is an acute national need for improved health physics radiation monitoring instrumentation and radiation calibration facilities. This initiative is designed to address this need. It involves cooperation throughout Energy Systems and the organization and development of a center known as Associated

Laboratories for Excellence in Radiation Technology (ALERT).

The purpose for ALERT centers on instruments, detectors, and other devices used for radiation measurements in health physics programs. ALERT will emphasize R&D related to such devices, an area that has been severely neglected in recent years. Other central functions of ALERT will include calibration and performance testing of various health physics devices. This will involve evaluation, maintenance, and quality assurance testing activities. The sharing of research advances, calibration information, and performance testing information with the scientific and technical community by technology transfer activities will be an integral part of ALERT.

The management of ALERT will be centered in the Health Sciences Research Division (HSRD) at ORNL because of the emphasis on health physics R&D activities. In addition to HSRD researchers, health physics instrumentation experts from the Instrumentation and Controls Division will function as a vital part of the research team. The combined radiation calibration facilities of Energy Systems will form the nucleus of the experimental portion of ALERT. Specifically, ALERT will make available the Radiation Standards and Calibration Laboratory in the Office of Safety and Health Protection at ORNL, HSRD's Radiation Calibration Laboratory, the Radiation Calibration Laboratory at Portsmouth Gaseous Diffusion Plant, and miscellaneous radiation sources and facilities at the Paducah Gaseous Diffusion Plant, the Oak Ridge Y-12 Plant, and the main ORNL site. Instrument maintenance and testing functions will also be shared among Energy Systems sites; most work is expected to be performed at ORNL and the Portsmouth Gaseous Diffusion Plant.

It is expected that ALERT will be certified by the National Institute for Standards and Technology (NIST) as a Secondary Standards Calibration Facility for Ionizing Radiation and will also become a national test facility for health physics instrumentation performance. In summary, ALERT is expected to meet Energy Systems calibration needs, the R&D needs of the health physics community, and national needs associated with performance test programs and NIST standards activities. Table 5.21 presents a summary of budget projections for this initiative.

Table 5.21
Budget projections by fiscal year for the Health Physics Instrumentation Center of Excellence Initiative[a]
($ in millions—BA)

	1994	1995	1996	1997	1998	1999
Total funding	2.1	1.7	1.7	1.6	1.6	1.6

[a]Funding is being sought from the Environmental Research and Development Program, HA.

Epidemiological Activities—HR

ORNL provides technical support to epidemiological activities conducted for the Assistant Secretary for Environment, Safety, and Health. Under HR01 05, support is provided for epidemiological research, including activities for the Radiation Effects Research Foundation. Under HR01 35, support is provided to K-25 Site worker safety studies. The HR-funded activities at ORNL were previously funded through the Biological and Environmental Research program in DOE-OHER and other DOE offices.

Office of Security Evaluations—HS

ORNL provides support to various activities associated with the development and maintenance of state-of-the-art analytical methods used in the review of safety analysis reports for packagings. These methods include computer codes and other advanced assessment tools.

Policy and Management Support for the Office of Nuclear Energy—KK05

DOE Standards Program • Since the late 1960s, ORNL has led in the management and overall conduct of standards development efforts, first for the Atomic Energy Commission and now for DOE. In this position, ORNL has established the program procedures and guidance for all participating DOE and DOE contractor organizations to implement DOE's standards policy as outlined in Order 1300.2A, "Department of Energy Technical Standards Program." This order, updated in May 1992, reaffirms the department's long-standing policy to use existing national/international standards or develop new departmental standards for its facilities, programs, and projects. ORNL responsibilities for the DOE Standards Program are

- to function as the DOE lead standardization organization, serving as the focal point within the department for registering new and ongoing standards development activities and carrying out technical/administrative program management;
- to develop new program procedures and a program manual for all involved organizations to follow in implementing the DOE standards policy;
- to develop a DOE standards index, identifying the various types of standards (international, nongovernment, federal, DOE, and program-specific) used or available for use by DOE and DOE contractor organizations and departmental and contractor personnel involved in standards development activities;
- to develop and conduct training (initial and ongoing) for DOE and DOE contractor personnel on the DOE Standards Program procedures; and
- to provide technical support for a DOE standards committee to arbitrate standards development/application issues that affect more than one department secretarial office.

DOE Performance Indicators Program • DOE, in a manner similar to the commercial nuclear industry, considers that facilities with good performance, as measured by an overall set of performance indicators, are generally recognized as well-managed facilities. The objective of DOE's performance indicators program is to collect data on key performance indicators and to have line management analyze and trend the data. ORNL compiles and prepares quarterly summary reports based on quarterly reports received from the senior officials in the DOE performance indicators program and performs special analyses of these data as requested.

Office of Nuclear Safety—NS

ORNL assists the Office of Nuclear Safety in the analysis of operational data from DOE facilities. Information to be analyzed is generally obtained from reports submitted in compliance with DOE Order 5000.3B or other formal reporting requirements. The Nuclear Operations Analysis Center in ORNL's Engineering Technology Division will continue to conduct engineering evaluations of events; participate in audits of the reporting requirements; prepare reports on events analysis, cause, and corrective action evaluations; and carry out events categorization and analyses of trends and patterns. The center conducts other operational information reviews related to specific facilities or groups of facilities.

Office of Civilian Radioactive Waste Management

ORNL's work in support of the DOE Office of Civilian Radioactive Waste Management (OCRWM) is funded by the Nuclear Waste Fund (program DB) and through work for others (WFO). ORNL's current activities involve waste and facility information and databases (DB03), transportation (DB04), systems engineering, environmental technical assistance, strategic and contingency planning (DB09), and transportation (WFO). The work has declined in scope from previous years as the OCRWM has transferred its activities to its new management and operating (M&O) contractor. The transportation work in the WFO area is being performed under a memorandum purchase order arrangement with this contractor. Funding for the ORNL program appears to be leveling out, as shown by the budget projections in Table 5.22.

Table 5.22
Office of Civilian Radioactive Waste Management major program summary by fiscal year
($ in millions—BA)

Budget and reporting code	Major program	1992	1993	1994	1995
DB and Work for Others	Office of Civilian Radioactive Waste Management	5.9	3.1	3.3	3.4
Percentage of total Laboratory funding		1.0	0.5	0.4	0.3

Nuclear Waste Fund—DB

Work in the DB03 area involves support for waste and facility information and databases, including completion of the Facility Interface Capability Assessment (FICA) work, continuing support of the Integrated Data Base (IDB), and support of transportation-related institutional activities. The FICA has resulted in the development of a global assessment of the ability of the nation's 122 reactors to accommodate various spent fuel shipping casks. The IDB is jointly funded and provides a comprehensive, top-level perspective on the wastes that must be handled by DOE in the future; it contains DOE's official spent fuel and radioactive waste inventories and projections through 2020.

Transportation support, in both the transport and systems engineering (DB04) and WFO areas, involves studying the development of support systems, assessing systems alternatives, and supporting testing of a tractor for pulling a legal-weight highway cask system. One major area will be the continued development of site-specific services planning documents for defining specific logistical interfaces between cask systems and reactor handling facilities. In addition, support will be provided in assessing proposals for new cask designs, in the development and maintenance of computer models needed by the OCRWM transportation project, and in supporting a case before the Nuclear Regulatory Commission for allowing burnup credit in cask designs.

The DB09 funding supports work in three areas. Systems engineering efforts include providing technical support to the Characteristics Data Base, which contains detailed information on the spent fuel and waste expected to be handled by the OCRWM program; initiating improved applications of and verifications and validation of the ORIGEN2 code used for projecting radionuclide inventories; and providing limited independent technical review and consultative support. Environmental technical assistance involves continuing support for the DOE Office of NEPA Oversight in evaluating environmental aspects of the high-level waste management program. Strategic and contingency planning provides support to the Office of Strategic Planning and

International Programs in evaluating and preparing strategic and contingency plans and strategy reviews of the OCRWM program.

Assistant Secretary for Environmental Restoration and Waste Management

ORNL receives funding from the Assistant Secretary for Environmental Restoration and Waste Management (DOE-EM) for (1) activities aimed at correcting existing problems, preventing future problems, and minimizing waste generation at the ORNL site, as described in Sect. 6, "Environment, Safety, and Health," and (2) R&D and technical support for addressing environmental restoration and waste management problems at DOE sites, with increasing emphasis on technology transfer to the public and private sectors. Most of the funding for activities at the ORNL site (see Table 5.23) is supplied through Energy Systems central organizations.

Table 5.23
Assistant Secretary for Environmental Restoration and Waste Management major program summary by fiscal year[a]
($ in millions—BA)

Budget and reporting code	Major program	1992	1993	1994	1995
EW10, EX10	EM Corrective Activities	3.1	17.5	19.0	27.1
EW20, EX20	Environmental Restoration	43.6	44.4	48.0	48.1
EX20	EM Isotope Facility Shutdown[b]	10.4	8.8	8.4	23.8
EW30, EX30	Waste Management	46.2	93.9	82.0	95.8
EW40	Technology Development	16.7	18.0	24.3	24.9
	Other[b]	5.7	10.5	2.5	5.5
Total		125.7	193.1	184.2	225.2
Percentage of total Laboratory funding		21.4	29.5	23.7	22.5

[a]Includes operating BA, capital equipment, and construction. Funding is provided by Energy Systems central organizations except as noted.
[b]Included in ORNL Financial Plan.

Environmental Restoration

ORNL provides support for DOE-EM's decontamination and decommissioning (D&D) program and remedial action projects (RAPs).

The D&D program covers surveillance and maintenance (S&M) of surplus sites that are contaminated with radioactive material and D&D of contaminated facilities. In combination with the Surplus Facilities Management Program (SFMP), the D&D program provides S&M to ensure the safety of DOE sites awaiting decontamination, planning for the orderly decommissioning of facilities, and a program to accomplish disposition of all facilities.

Major ORNL activities in RAPs include conducting radiological surveys on private properties near inactive mill tailings sites [Uranium Mill Tailings Remedial Action Project (UMTRAP)] and at facilities that were formerly used under contract with the Atomic Energy Commission [Formerly

Utilized Sites Remedial Action Project (FUSRAP)]. The radiological status of sites involved in DOE's RAPs is identified, characterized, and verified to provide a basis for the reduction of the health impacts of fuel cycle activities. Advancement of the state of the art in equipment and methodology is an integral part of this work.

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

Funding for FUSRAP is expected to remain level through FY 1995. SFMP funding is expected to increase significantly as the level of decommissioning effort at federal facilities increases. ORNL will verify that these facilities are decontaminated in accordance with established DOE guidelines.

New approaches, processes, and technologies are required to tackle many of the pressing environmental restoration problems facing DOE. R&D coupled with demonstration, testing, and evaluation (RDDT&E) is critical to fostering cost-effective solutions to these problems. An important part of the ORNL effort is directed toward RDDT&E in direct support of real problems at DOE sites, as exemplified by the X-231B Technology Demonstration. This project was initiated at the Portsmouth Gaseous Diffusion Plant to find a feasible and cost-effective solution to treatment of a land treatment unit contaminated with mixed waste. As a result of numerical modeling, laboratory experimentation, and full-scale field testing, a novel approach was demonstrated. This approach couples selected physicochemical processes in continuously mixed subsoil surface reactors. Treatment processes can be used individually or in combination to vaporize, oxidize, or immobilize contaminants in situ. Treatment can be accomplished effectively (e.g., >85% efficiency) and rapidly (e.g., 20 ton/h) while limiting worker exposure and controlling the fate of volatile organic compounds (VOCs) and radioactive substances. Moreover, the costs of in situ treatment were substantially lower than those of available ex situ technologies. The processes demonstrated at the Portsmouth plant are being used there for closure and remediation of the X-231B and similar solid waste management units, at estimated savings of several million dollars. Plans are in place to conduct an increasing number of projects such as this to yield better, faster, and less expensive solutions.

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

The Energy Systems Groundwater Program Office (GWPO) promotes consistency among groundwater activities at the five DOE facilities managed by Energy Systems and acts as a focal point for technical and programmatic interactions with the public and with state and federal regulatory agencies. Groundwater protection program coordinators at each site are responsible for oversight of all groundwater activities at their sites and for facilitating integration of requirements of the compliance and environmental restoration groundwater programs. The Oak Ridge Hydrology Support Program provides technical support to the GWPO to assist in achieving technical consistency and defensibility across the site programs and to facilitate the sharing of lessons learned. This effort is expected to grow in 1993 to include at least one technical support staff member for each site, enhanced support for data management, and expanded work in groundwater modeling, which will draw on the Laboratory's new supercomputing capabilities. See "Applied Mathematical Sciences—

KC07" in this section and Sect. 4, "Summary of Major Initiatives," for discussions of the groundwater Grand Challenge work.

Waste Management

Waste management activities at ORNL are discussed in Sect. 6, "Environment, Safety, and Health." These activities include the operation of 34 facilities, ongoing upgrades of ORNL waste management facilities needed to support the programmatic missions of DOE, management of wastes produced by previous operations and research, and waste minimization activities.

Technology Development

The DOE-EM Office of Technology Development (OTD) is charged with developing and demonstrating new technologies for dealing with DOE's environmental restoration and waste management problems. The Energy Systems Office of Environmental Technology Development (formerly the Office of Waste R&D Programs) manages a diverse program of technology development to address these problems. The program involves (1) developing new technologies and demonstrating or modifying existing techniques to ensure application of the most cost-effective and technologically advanced remediation and waste management methods and (2) developing energy-efficient waste minimization technologies. This work is conducted at ORNL, the Oak Ridge Y-12 Plant, and the Oak Ridge K-25 Site. The technologies being developed are shared among DOE sites and with the private sector for use in solving similar environmental problems. Program components include:

- Transportation—database evaluation and site verification to develop an understanding of site-specific needs; systems engineering to systematically evaluate methods of meeting transportation requirements for a reasonable number of applications, including hazardous and mixed waste remediation efforts; risk assessment and regulatory support to define the requirements for on-site and off-site transport of hazardous and mixed waste; and base technology development to evaluate the effect of hazardous substances on packaging components.
- Bioremediation—microorganisms that can fix, degrade, detoxify, or accumulate select organic materials [tetrachloroethylene, trichloroethylene, polychlorinated biphenyls (PCBs)] and inorganic materials (uranium, strontium, cesium, lead, cadmium, copper) in situ or in process.
- Characterization—modeling of hydrologic systems; advanced field measurement and sensing methods; improved systems for data collection, analysis, management, and display; biomarker and biosensor instrumentation to monitor contaminant behavior and response to remediation strategies using improved, less costly, analytical means in situ and in real time; and field-oriented methods that allow characterization of sites and contaminants with minimal cost, health, and safety impact.
- D&D—decontamination and decommissioning of metals and concrete to assist in the decommissioning of formerly utilized facilities and in the replacement of several major facilities in the Defense Programs Reconfiguration.
- Technology transfer—facilitation of the transfer of technologies that could improve program and operational effectiveness, reduce costs, and save time, among federal agencies, industry, academia, and the international community.
- Robotics—robotic systems and remote technology that can enhance environmental restoration and waste management operations by removing workers from radioactive, hazardous, and mixed waste; increasing speed and productivity of characterization and remediation; and reducing life-cycle costs.
- Treatability—inorganic membrane technology for in situ remediation of chromic acids, heavy metals, VOCs, and other organics in landfills; in situ immobilization, thermal treatment, and/or

advanced oxidation for the treatment of soils contaminated with VOCs and low levels of radioactive substances; and in situ vitrification to instantly destroy many hazardous components and immobilize the remainder in a glass or slag matrix.

- Waste minimization—action that minimizes the volume or toxicity of waste by recycling, recovery, and reuse of materials; source substitution; and process modification to reduce the production of radioactive, hazardous and mixed wastes at the generation point.

Although some of these technologies are currently developed, much more refinement and advancement are necessary for their cost-effective application to increasingly challenging waste problems. Significant industrial involvement is expected, especially during the demonstration phase of the technologies; this will require an efficient transfer of new technologies for application both to and from the DOE facilities.

In an effort to increase the number of qualified scientists and engineers, this program sponsors joint research projects with universities and minority institutions to encourage students to study in fields applicable to environmental restoration and waste management.

Significant recent accomplishments include the pilot-scale demonstration of in situ vitrification of a trench containing radioactive materials; demonstrations of direct sampling ion trap mass spectrometry (providing real-time measurements of trichloroethylene and perchloroethylene) at the Savannah River Integrated Demonstration Site and of a derivative ultraviolet absorption spectrometer that measures benzene and toluene in real time during dynamic underground stripping at Lawrence Livermore National Laboratory; remote site characterization using a U.S. Army Soldier Robot Interface Project testbed; and remote surface mapping of waste in silos at Fernald. Also, a CRADA with the General Electric Company was established to share funding and research results in the area of bioremediation of PCBs. A more basic research effort is under way to develop spectroelectrochemical, surface-enhanced Raman technology for monitoring of a wide range of chlorinated aliphatic components in groundwater.

Funding is anticipated to increase over the planning period. The budget projections for these programs are presented in Table 5.24.

Table 5.24
Budget projections by fiscal year for the Office of Environmental Technology Development
($ in millions—BA)

	1993	1994	1995
Operating expense	30	40	41
Capital equipment	2	2	2

Quality Assurance and Quality Control

The Office of Environmental Oversight (EM-22) in the DOE-EM Office of Oversight and Self-Assessment (EM-20) is responsible for

- developing and coordinating written guidance to assist EM-wide program offices in implementing DOE policies and standards regarding federal, state, and local environmental requirements pertaining to
  - the treatment, storage, and disposal of waste,
  - corrective actions, and
  - cleanup of inactive facilities and sites;
- determining the need for and implementing appropriate EM-wide training in specific technical and policy-related areas;

- providing independent review of environmental compliance documents—including NEPA documents, primary Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) documents, and documents prepared in response to Resource Conservation and Recovery Act (RCRA) compliance agreements and consent orders—developed for EM activities; and
- providing independent oversight and appraisal of environmental compliance within EM.

The ORNL Environmental Sciences Division has acquired extensive expertise in these areas and will assist EM-22 in its EM-wide document review, guidance, training, and auditing functions. A high-priority activity in this area is development of guidance for efficiently integrating CERCLA, NEPA, and RCRA documentation and requirements for EM activities.

West Valley Demonstration Project Vitrification Facility—EX70

ORNL is supporting the West Valley Demonstration Project Vitrification Facility, a DOE-funded facility to demonstrate the solidification of high-level radioactive waste. The project is being carried out by West Valley Nuclear Services (WVNS).

ORNL provides engineering assistance to WVNS on the control system for the Vitrification Facility Transfer Cart Project. Specifically, ORNL's effort includes controls, signal transmission, and electrical equipment related to the transfer cart. ORNL has previously developed similar technology for (1) radiation-hardened, wireless signal transmission in metal-lined facilities and (2) remotely controlled, battery-operated vehicles in remote environments. ORNL has carried out Title I design. The remaining phases are Title II Design and Title II Engineering Support.

Energy Information Administration

ORNL will continue its support of the Energy Information Administration (EIA) through (1) economic analysis in support of issue analysis and in support of EIA's ongoing energy modeling activity, (2) analysis and evaluation of EIA's quality assurance activities, particularly through expert reviews, and (3) technical analyses including engineering studies. In addition, ORNL will apprise EIA of new developments in the following areas of expertise:

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

A National Energy Information System would provide a coordinated approach and a center of responsibility by which the objectives and technical needs of the EIA may be met (Table 5.25). Funding for future years is expected to be stable in real dollars.

Table 5.25
Energy Information Administration major program summary by fiscal year
($ in millions—BA)[a]

Budget and reporting code	Major program	1992	1993	1994	1995
TA	Collection, Production, and Analysis	0.8	0.3	0.4	0.4
Percentage of total Laboratory funding		0.1	<0.1	<0.1	<0.1

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

Other DOE Programs and Installations

ORNL continues to provide support to other DOE offices and installations, including the Office of the Associate Deputy Secretary for Field Management; the Assistant Secretary for Policy, Planning and Program Evaluation; the Federal Energy Regulatory Commission; other DOE contractors and operations offices; and other Energy Systems sites. Funding levels are given in Table 5.26.

Table 5.26
Funding for support of other DOE programs and installations by fiscal year
($ in millions—BA)[a]

	1992	1993	1994	1995
Office of the Associate Deputy Secretary for Field Management	0.7	0.4	0.5	0.5
Assistant Secretary for Policy, Planning and Program Evaluation	2.5	2.5	2.5	2.5
Federal Energy Regulatory Commission	2.0	0.5	1.2	1.2
DOE contractors and operations offices	33.6	23.3	20.8	23.1

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

Office of the Associate Deputy Secretary for Field Management

In-House Energy Management—WB • ORNL is conducting energy management studies in Laboratory facilities to identify retrofit projects that will allow achievement of the energy consumption and efficiency goals established by DOE and reflected in ORNL's ten-year energy management plan. The goals in the plan are addressed through a comprehensive Energy Management Program. The program's elements integrate energy conservation activities specific to the Laboratory's buildings, processes, vehicles, and equipment. For example, retrofit projects include projects identified through completed surveys and studies that improve building and process operation energy efficiency.

Several studies are in progress at ORNL to determine whether energy conservation retrofit projects can be economically justified. Six retrofit projects have been identified and funded. These projects will upgrade the inefficient heating, ventilation, and air conditioning (HVAC) control systems in several buildings and provide a centralized computer-based utility metering system as well as a chilled water free-cooling heat exchanger for the central chilled water system.

Strategic Facilities Utilization Program • The Strategic Facilities Utilization Program (SFUP) was a DOE-sponsored program to upgrade or demolish abandoned and unusable facilities that

spanned the period from FY 1987 to FY 1991. Program closeout was extended into FY 1993 for completion of documentation and testing. Through SFUP, ORNL demolished several buildings, relocated a prefabricated bus stop, and restored the New Bethel Church for use as a visitor center. Many other potential projects were identified as part of SFUP. These projects are now at the top of our continuing strategic facilities list.

Assistant Secretary for Policy, Planning and Program Evaluation

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

ORNL supports the Office of Environmental Analysis (OEA) in the development of energy resource assessment models and in the provision of background research for various energy and environmental policy issues. OEA is funding a variety of projects, including a flue-gas desulfurization information system, development of a residual generating model for the National Energy Modeling System, analysis papers to support OEA's role in the National Energy Strategy process, studies of international developments in global climate change, a study of the relationships between automotive fuel economy and hydrocarbon emissions, research on the physical and ecological effects of climate change, research on the economic valuation of energy-related environmental impacts, and studies of the impacts of environmental policies on electric utilities. A major effort is in progress to analyze fuel cycles and to provide estimates of (1) the physical impacts on environmental resources, including human health and safety, and (2) costs and resulting potential effects on market prices for major fuels.

ORNL also provides support to the Office of Electricity/Coal/Nuclear & Renewable Policy on hydropower issues. For example, ORNL studied the feasibility of a hydropower environmental mitigation information analysis system. If DOE continues to support this concept, additional long-term funding may be received.

ORNL is actively involved in developing a new DOE mission and associated program related to the energy needs of developing nations. The Assisting the Deployment of Energy Practices and Technologies (ADEPT) Program includes needs studies, technical information, institution building, training, technology adaptation, and technology demonstration. ORNL roles include project activities and program support. In addition, ORNL is supporting the development of an Energy Efficiency Strategy Assistance Program (EESAP).

Federal Energy Regulatory Commission

ORNL provides assistance to the Federal Energy Regulatory Commission (FERC) in two major areas: evaluation of the environmental impacts of licensing new hydroelectric projects and compliance with environmental conditions at existing hydroelectric projects. Ongoing work includes several site-specific environmental assessments for hydroelectric projects in the Central Valley of California, where major water rights issues are being addressed, and in the state of Washington, where multiple small-scale projects are proposed in the Skagit and Nooksack river basins. This work involves development of complex water routing models and mitigation solutions to challenging issues such as biodiversity, the spotted owl, and water use for drinking vs maintenance of fish populations.

Relicensing of existing projects has become a major effort for the FERC, and staff are also being challenged to define methods to enhance an environment that may have been affected by 50 years of hydropower operation.

Other DOE Organizations

ORNL performs numerous small tasks, frequently on an ad hoc basis, for a number of other organizations within DOE, including the Assistant Secretary for Congressional, Intergovernmental and International Affairs; the Economic Regulatory Administration; DOE-ORO; and others. These activities are distributed among the various Laboratory programs and together make up about 5% of the total Laboratory funding.

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

ORNL's Energy Division conducts program evaluation research for the Bonneville Power Administration's Office of Energy Resources. Bonneville has operated a Residential Weatherization Program since 1981. ORNL's research has evaluated the energy saved by this program over time and has expanded into issues concerning the energy efficiency of new residential buildings, compliance with Bonneville's Model Conservation Standards, the fuel choices of customers, and integrated resource planning. The Energy Division will extend its leadership in the fields of artificial intelligence and power systems by developing a system to monitor Bonneville's substation equipment in real time to support reliability-centered maintenance.

Staff from the ORNL Health Sciences Research Division (HSRD) are conducting projects involving the development or demonstration of portable techniques for detecting organic chemical components at or near hazardous waste sites. Derivative ultraviolet absorption spectroscopy using fiber-optic cables can be used to detect benzene, gasoline, and other contaminants in groundwater with a very rapid response (<1 min) using rugged, lightweight instruments. Spectrochemical techniques are expected to be equally successful in the detection of trace amounts of chlorinated hydrocarbons in soil and groundwater.

DOE's Office of Arms Control is supporting efforts to develop rapid, portable methods for detection of airborne chemical agents. HSRD staff have been applying the technique of surface-enhanced Raman spectroscopy to this problem. Laboratory work has revealed the technique to be both rapid and sensitive. Field tests are needed to see if there is sufficient selectivity under real world conditions.

ORNL is providing assistance to the DOE Rocky Flats Office in preparing environmental compliance documentation for proposed cleanup activities, including the Residue Elimination Program.

Other Energy Systems Sites

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

In addition, the Energy Systems Groundwater Program Office (GWPO) and the Oak Ridge Hydrology Support Program are managed through ORNL's Environmental Sciences Division. The GWPO promotes consistency among groundwater activities at the DOE facilities managed by Energy Systems.

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

Other ORNL Programs

Reactor Operations

The Research Reactors Division (RRD), which reports to the ORNL Associate Director for Reactor Operations, oversees the operation, maintenance, and support of ORNL's research reactors so that they safely, reliably, and efficiently fulfill their intended functions in isotope production, research, and training. The RRD works with 11 other ORNL divisions and organizations that either conduct reactor-based research or support reactor operations. Programmatic funding support is received from DOE's Office of Energy Research (DOE-ER), and oversight is provided by the Office of Nuclear Energy (DOE-NE) and the Oak Ridge Operations Office (DOE-ORO).

ORNL management is committed to maintaining a proactive approach in operating the Laboratory's research reactors. This approach includes securing all resources necessary to ensure safe, efficient, reliable operation; the support of top management; and a continued commitment to excellence. The Total Quality Management (TQM) philosophy will continue to be emphasized, as will environmental, safety, and health requirements; Institute of Nuclear Power Operations guidance; and compliance with the regulations of DOE, the Occupational Safety and Health Administration, the Environmental Protection Agency, and the Department of Transportation.

ORNL currently operates one Category A reactor, the High Flux Isotope Reactor (HFIR). Use of HFIR is expected to continue for

- production of transplutonium isotopes,
- neutron scattering studies for materials science,
- production of high-specific-activity radioisotopes (for medicine, industry, and research),
- materials irradiation, including testing of fuel for the Advanced Neutron Source (ANS) project,
- gas-cooled reactor fuel studies, and
- neutron activation analysis.

Recognizing that excellence can only be achieved through continuous improvement, reactor operations staff regularly initiate enhanced methods, processes, and procedures.

Improved relations with users are being emphasized by establishing a reputation for reliability; projecting and adhering to forward-looking, 60-day operating schedules using the HFIR Users Committee to resolve competing demands; enhancing user indoctrination and training; and monitoring user satisfaction.

Both near- and long-term spent fuel disposition solutions are also receiving priority attention. In the near term, total in-pool storage is being increased to 54 spaces. Efforts for the long term include obtaining a shipping container to transport spent cores; a lease-purchase agreement has been successfully negotiated.

At the Tower Shielding Reactor II (TSR-II), the Japanese/American Shielding Program of Experimental Research (JASPER) ended with the completion of the final Phase VIII, Special Materials. An excellent performance record was achieved in support of JASPER; however, TSR-II was shut down following completion of the JASPER program at the end of FY 1992 because of

insufficient specific programmatic need and a lack of firm financial commitment. A shutdown plan has been prepared and submitted to DOE for approval.

Other ORNL reactors include the Oak Ridge Research Reactor (ORR), the Health Physics Research Reactor (HPRR), the Bulk Shielding Reactor (BSR), and the Critical Experiments Facility (CEF), all of which have been shut down. ORR has been defueled, and plans call for its transfer to the DOE Office of Environmental Restoration and Waste Management (DOE-EM) in late FY 1993. HPRR has also been defueled, and its Technical Specifications have been cancelled. Consideration is being given to transferring the reactor to Los Alamos National Laboratory. The HPRR reactor building has been converted to space for storage of HFIR spare parts. A shutdown plan for BSR has been prepared and submitted to DOE for approval.

With approval of an alternative method for measuring fresh fuel at HFIR before fuel loading, the CEF is no longer required. Its Technical Specifications have been cancelled, and the facility has been transferred to the Oak Ridge Y-12 Plant for inclusion in plans to transfer the building containing the CEF to DOE-EM.

The Pool Critical Assembly (PCA) is in standby status. A programmatic initiative has been proposed to retain the PCA in support of training and education activities for a broad range of users, including the University of Tennessee, Louisiana State University, Mississippi State University, the Oak Ridge Institute for Science and Education, and DOE. (See "Office of Energy Research" earlier in this section.)

A second programmatic initiative, also proposed earlier in this section (see "Office of Energy Research"), calls for the establishment of a Center for Excellence in Research Reactors (CERR). The CERR will help to ensure that access to irradiation facilities in nuclear reactors is readily available to meet national research, development, and educational needs.

Support and involvement in the development and construction of ANS, which will ultimately replace HFIR, will be a significant mission for Reactor Operations. Several goals for Reactor Operations have been identified:

- maintaining a high state of morale and esprit;
- emphasizing improvement of DOE Order 5000.3B reporting performance through staffing, critiques for all unusual occurrence reports and appropriate off-normal occurrence reports, implementing trending data feedback, and suggesting use of the same reporting criteria by all contractors;
- implementing "commitment to excellence" initiatives while reducing operating costs;
- taking leadership roles in the Association for Excellence in Reactor Operations Council and Working Groups;
- coordinating external audits, evaluations, reviews, and assessments to minimize their impact on operating and support staff;
- improving relationships with DOE-ER, DOE-NE, and DOE-ORO to an excellent state, as viewed by these sponsors, customers, and regulators;
- improving productivity of people who are assigned to or are members of the organization;
- empowering people; and
- implementing a TQM program integrated with the existing Performance Indicators Program.

In short, the aim of the Reactor Operations organization is to earn a reputation for being DOE's best reactor M&O contractor.

Robotics and Intelligent Systems Program

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

RISP addresses R&D goals for extending human senses and dexterity into unstructured hostile environments. The goals are to develop systems that minimize human risk by allowing effective remote operations in hazardous environments while also minimizing human error and enhancing overall system efficiency through automation of routine or repetitive tasks. The research includes developing an appropriate combination of teleoperation and autonomous operation to achieve the necessary level of task performance while maintaining robust human-machine interaction. The programs cover activities in basic R&D as well as development and full-scale demonstrations of system prototypes, including remote operations and maintenance.

RISP performs R&D for five major DOE programs. Research into intelligent machines is performed for DOE's Office of Basic Energy Sciences Engineering Research Program. Development of robotic systems and techniques to perform surveillance and manipulation functions within a nuclear power plant is pursued for DOE's Office of Nuclear Energy. For DOE's Office of Fusion Energy, RISP performs remote equipment design and remote mock-up demonstrations for the Tokamak Physics Experiment and remote system planning and development support for the International Thermonuclear Experimental Reactor. Efforts for the DOE Office of Environmental Restoration and Waste Management involve national planning and technology development and demonstration of robotics technology for support of national restoration efforts. Key areas of focus for ORNL include underground storage tanks, buried waste retrieval, contaminant analysis automation, waste processing operations, waste facility operations, cross-cutting and advanced technologies, and decontamination and decommissioning. RISP also provides technical support to ongoing environmental restoration projects on the Oak Ridge reservation. A new activity in FY 1993 is support for the DOE-AMTEX partnership, which applies the resources of the national laboratories to the problems of the American textile industry (see Sect. 7, "Technology Transfer and Science and Mathematics Education").

Under the auspices of the U.S. Army Human Engineering Laboratory, RISP personnel are contributing to the Robotics Test Bed Program, an element of the Office of the Secretary of Defense Unmanned Ground Vehicles Master Plan Program, which is assessing opportunities for new robotic combat functions. A number of programs are being performed under the sponsorship of the U.S. Army Program Manager Office for Ammunition Logistics. These programs include the development of vehicles to rapidly rearm battle tanks and self-propelled artillery pieces, systems to process ammunition rounds before loading them onto the rearm vehicles, and paperless accounting systems based on high-density, machine-readable symbologies.

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

Work for Others

Work undertaken for federal agencies other than DOE, nonfederal agencies, private organizations, and the Nuclear Regulatory Commission (NRC) accounts for about 15% of the Laboratory's total budget. As shown in Table 5.27, the level of funding for work for others (WFO) is expected to remain relatively stable over the next several years. The distribution of work for non-DOE sponsors is expected to change, moving from an emphasis on Department of Defense (DOD) support to other agencies as the defense budget declines. An increasing amount of the WFO work is

expected to involve support from private industry in terms of technology transfer or Laboratory-industry partnerships.

In FY 1993, Laboratory management reorganized the WFO Steering Committee and formed a new WFO strategic planning group called the Enterprise Team. Composed of representatives from each Laboratory division, this team is responsible for defining priorities for ORNL's WFO program to ensure that new WFO projects are compatible with the Laboratory missions.

The Enterprise Team is the principal vehicle whereby new cross-division, multidisciplinary efforts are conceived and initiated. The emphasis is on large projects that cut across research divisions rather than on small efforts that tend to be started by individual staff members. An example of a cross-cutting effort is the Transportation Technologies and Systems initiative (described in Sect. 4, "Summary of Major Initiatives"), which was "brainstormed," organized, and initiated by the team.

Table 5.27
Work for Others program resource summary by fiscal year
($ in millions—BA)[a]

	1992	1993	1994	1995
Federal organizations				
Nuclear Regulatory Commission	20.7	18.9	20.3	20.0
Department of Defense	37.1	48.8	41.9	36.3
National Aeronautics and Space Administration	5.0	5.9	6.2	10.1
Department of Health and Human Services	3.8	2.8	4.3	4.9
Environmental Protection Agency	3.4	1.1	2.2	2.2
National Science Foundation	0.9	1.0	1.0	1.0
Federal Emergency Management Agency	1.3	1.4	1.1	0.0
Agency for International Development	0.4	0.1	0.3	0.5
Department of Transportation	4.4	2.8	4.1	3.1
Other federal agencies	4.8	(1.0)	5.9	9.5
Nonfederal organizations				
Electric Power Research Institute	2.2	1.8	1.7	1.8
Other nonfederal organizations	3.9	5.3	4.2	4.9
Total	87.9	88.9	93.2	95.3

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

Much of the existing WFO effort at ORNL consists of relatively small (<$500,000) projects. This emphasis on small projects tends to dilute the efforts of staff and to consume a disproportionate amount of support staff. Increasing the number of large (>$5 million) projects would allow for more efficient use of staff and resources.

The goal over the next several years is to transform the current program into a more balanced split between large and small projects. Achieving this goal may require broader collaboration with other parts of the Oak Ridge complex as well as other national laboratories. In FY 1993, we initiated an ad hoc collaborative effort with the Office of Technology Transfer, the Hazardous Waste Remedial Action Project (HAZWRAP), Data Systems Research and Development (DSRD), the National Security Program, and several other R&D programs to explore new ways of effectively responding to new opportunities that might involve WFO.

ORNL staff are also participating in the Added Factor/Waiver Policy Task Team chartered by DOE's Work for Others Working Group. This team is focusing its efforts on establishing added factor waiver criteria and procedures.

Federal Organizations

ORNL funding from non-DOE sponsors is generally expected to remain at present levels or to increase in the coming years, with the exception of support from DOD. The following is an agency-by-agency description of the proposed work.

Nuclear Regulatory Commission

ORNL efforts for the Nuclear Regulatory Commission (NRC) reflect the NRC's priorities: response to public attitudes requiring a high degree of confidence in the safety of nuclear power, the maturing of the current generation of U.S. nuclear reactors, and certification of the next generation of reactors. Completion of the more than 100 nuclear plants ordered in the 1960s and 1970s, coupled with the upcoming expirations of operating licenses for many of these plants, has shifted the emphasis of NRC research toward structural and component safety issues, structural aging research, analysis of reactor operational data, advanced instrumentation and diagnostics, accident sequence analysis, and license extension requirements.

The NRC is also looking toward the future by working to certify advanced light-water reactor (LWR) designs. ORNL funding from the NRC has increased significantly during the past three years and is expected to remain fairly stable over the next several years. Some of the past increases are supporting ORNL projects that provide a technical basis for the NRC design certification for advanced reactors (e.g., advanced LWRs). Funding has also increased for technical assistance to NRC staff responsible for regulating the operating nuclear reactors. Environmental and waste management issues remain important and offer potential for additional research involvements.

ORNL performs work primarily for four offices within NRC: the Office of Nuclear Regulatory Research (RES), the Office for Analysis and Evaluation of Operational Data (AEOD), the Office of Nuclear Reactor Regulation (NRR), and the Office of Nuclear Material Safety and Safeguards (NMSS). RES, the major sponsor of ORNL activities, conducts comprehensive research programs that lead to regulatory guidelines and standards issued by the NRC. NRR is charged with implementing regulations dealing with licensing and inspection of the commercial nuclear power industry; these regulations draw heavily on knowledge obtained from research programs. AEOD collects, analyzes, and evaluates operational safety data to identify areas requiring NRC or industry action. NMSS is charged with overseeing public health and safety licensing activities in the nonreactor nuclear arena.

Nuclear Regulatory Research • During the next several years, the NRC will continue to give priority to investigating long-term behavior of reactor pressure vessels, severe accident issues, and issues relating to extension of the operating licenses of existing power plants beyond their original 40-year period. Research on the aging characteristics of plant components has contributed new technologies for nonintrusive evaluation of nuclear plant piping and valves. Technology transfer for some of these developments is occurring through licenses granted to private-sector companies. Another research effort at ORNL is developing both a structural aging handbook and a materials property database for aging concrete structures in U.S. nuclear power plants.

Research on fission product behavior for LWRs under severe accident conditions has decreased somewhat, but ORNL projects are continuing to help resolve regulatory issues in this area. Recent work has provided a basis for possible modifications of the portions of NRC Regulatory Guides 1.3 and 1.4 that deal with iodine chemical forms in containment. Projects in this area are expected to continue at a constant level of effort for the next several years.

Other research initiatives at ORNL are contributing to the NRC's Severe Accident Research Plan (documented in NUREG-1365, Rev. 1). These efforts include work on boiling-water reactor (BWR) core-melt progression and in-vessel strategies for addressing potential severe accident conditions. ORNL staff collaborate with Sandia National Laboratories and Idaho National Engineering Laboratory to improve the MELCOR code for LWRs and extend its applicability to scenarios for severe accidents in BWRs. Other severe accident code development work supports NRC cooperative research agreements with Germany (CORA-BWR experiments) and with seven other nations to develop and validate computer codes for modeling fission product behavior and core-melt progression under severe accident conditions (Cooperative Severe Accident Research Partners).

The NRC continues to place high priority on research to ensure the integrity of reactor pressure vessels in commercial nuclear power plants. ORNL is the lead laboratory for this work, which includes the Heavy-Section Steel Technology (HSST) program, the Heavy-Section Steel Irradiation (HSSI) program, and the Surveillance Data Base, Analysis, and Standardization (SAS) program.

The HSST program investigates issues concerned with validating safety margins for prevention of reactor vessel fracture under all feasible loading conditions. Large-scale fracture experiments and advanced analyses are being performed to investigate shallow flaws and localized thermally induced constraints associated with emergency core-cooling scenarios. In FY 1992, pressure vessel investigations were expanded to include supplemental pressure vessel safety research for advanced LWR designs and for the advanced reactors that the NRC is working to certify.

The HSSI program is extending databases and the basic understanding of physical mechanisms associated with radiation-induced damage (e.g., embrittlement) in pressure vessel steels. Radiation experiments are also performed to verify the applicability of damage models to prototypically thick steel sections. One aspect of the program is a study of the degree to which degraded steel properties recover when thick sections of irradiated steel are annealed at relatively high temperatures for sustained periods of time. R&D activities relating to reactor pressure vessel integrity, particularly the fracture mechanics and irradiation embrittlement studies, are important to the NRC and to the nuclear industry.

The SAS program maintains the national operational surveillance database on embrittlement for commercial reactors. These data are used to develop improved correlations for predicting the state of embrittlement for vessels in operating reactors. These results have direct applications in license renewal and life-extension assessments, which will continue to be major NRC concerns. Increased attention is being given to determining the compatibility of data from other nations with the U.S. database and to possible use of these data in a combined manner. ORNL leads the NRC effort to develop and examine an international database on embrittlement; this effort is coordinated with the International Atomic Energy Agency.

A generic environmental impact statement appropriate for license renewal rulemaking was developed with ORNL assistance and listed in the Federal Register for public comment. ORNL is working with the NRC to assess the comments and assist in the resolution process.

The NRC sponsors safety research to support certification of advanced LWRs. ORNL provides support in the areas of thermal hydraulics code validation, assessment of severe accident evaluation, instrumentation and controls (I&C) methodologies, and pressure vessel and materials studies. As the NRC extends its considerations of advanced reactor designs, ORNL's support efforts are expected to increase. Projects in this area include assessments of advanced digital I&C systems, material studies, and severe accident analyses.

Additional ORNL projects for RES were recently started in the areas of human factors research and evaluation, engineering systems assessments, and review of radioactive transport specification packages.

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

Analysis and Evaluation of Operational Data • AEOD's mission within the NRC is to serve as a focal point for the continuing independent assessment of operational performance of nuclear power plants. Projects sponsored by AEOD at ORNL emphasize the collection, review, analysis, and evaluation of plant safety performance data. The pioneering Accident Sequence Precursor Project identifies nuclear power plant events that are considered precursors to potential severe core-damage accidents and uses risk assessment methodologies to determine the quantitative significance of events. ORNL is assisting in the resolution of operational performance issues, benchmarking the operating records of individual power plants for diagnostic assessments, trending events, providing technical assistance, and responding to inquiries from NRC staff.

ORNL operates and maintains the NRC's official database on reportable operational events at commercial power plants—the Sequence Coding and Search System (SCSS). Used by the NRC to construct event sequences, the SCSS is a highly structured system that supports detailed searches of operational occurrences. ORNL also maintains data systems on reactor events in other nations, international incident reports, and power plant performance indicator data and appropriate statistical models developed for the interpretation of these data. ORNL provides extensive support to AEOD through the NRC's performance indicator program by evaluating events to determine their cause, monitoring changes in plant performance, and indicating corrective actions needed to prevent serious problems. ORNL is assisting AEOD in the development of a quarterly publication, *Power Reactors: Events and Issues*, which will highlight case studies and evaluations performed by AEOD to provide feedback on "lessons learned" from these events for the nuclear industry.

Nuclear Reactor Regulation • Using expertise developed in RES programs, ORNL provides technical consultation and assistance to NRR. Technical assistance is currently provided in the interpretation of data from nonintrusive plant component evaluation, in analyses of fuel stability, in the review of licensing documentation, in evaluations of BWR stability phenomena, and in failure modes and effects analysis. A significant effort involves investigations of the thermal-hydraulic stability of BWR cores or fuel assemblies. Work at ORNL also includes analyses of potential accident sequence precursor events occurring during low-power or shutdown operations, evaluations of materials irradiation test data, low upper-shelf energy welds, and water chemistry standardization for nuclear power plants.

ORNL has provided technical assistance in updating NRC's health physics positions on inspection, enforcement, and licensing issues. The Health Physics Positions Database is used both by headquarters and regional staff to ensure uniformity in licensing actions.

Economic analyses and reviews of safety-related systems are being conducted to support the NRR's advanced reactor design certification efforts. Further increases in NRR work are expected during the next few years to assist NRC's advanced reactor design review and nuclear plant license extension activities.

Nuclear Material Safety and Safeguards • The NMSS sponsors several projects at ORNL, including computer programming and documentation of criticality safety, shielding and thermal analyses of nuclear fuel facilities and package designs, licensing of enrichment facilities, and review of terminated license files for radioactive materials handling facilities. In other NMSS projects, ORNL provides technical support in reviewing the design, construction, operation, and performance of low-level waste facilities and assists in developing a national profile on commercially generated low-level radioactive mixed waste.

Technical assistance is provided for assessing the effectiveness of the low-enriched uranium (LEU) Reform Rule and its implementation in maintaining the NRC's desired level of safeguards for users of nonstrategic special nuclear materials. Terminated license files are reviewed to determine whether the sites and licensees were demonstrated to meet present criteria for release of the site, based on public health and safety considerations, and whether the information provided by the licensee was sufficient to determine releasibility. Funding for NMSS work is expected to remain relatively stable or to increase over the planning period.

Other Offices • ORNL provides technical assistance in the conduct of inventory verification, analysis of special nuclear materials samples, preparation of site-specific material standards, and review of environmental assessments and operating procedural changes. ORNL staff members also provide consultation and technical assistance to the NRC Advisory Committee on Reactor Safeguards.

U.S. Department of Defense

ORNL carries out R&D for the major DOD services—the Army, Navy, Marines, and Air Force—as well as for joint agencies such as the Defense Nuclear Agency, the Advanced Research Projects Agency (ARPA), the Ballistic Missile Defense Organization [formerly the Strategic Defense Initiative Organization (SDIO)], and the U.S. Transportation Command (USTRANSCOM). Several projects, such as the Survivable Optics Manufacturing Operations Development and Integration Laboratory (MODIL) and the Seawolf project, are managed by non-ORNL Energy Systems organizations, and all projects are considered part of an Energy Systems central organization.

Army • ORNL research for the Army includes programs in materials science and technology, optics, instrumentation and control systems, robotics and intelligent systems, man-machine interface technology, transportation systems, operations research, and environmental and manpower analysis. In addition to the Army-funded projects, ORNL also has an optics development program, funded by the Army Strategic Defense Command and the Ballistic Missile Defense Organization, on mirrors, baffles, and windows for broadband-type sensors.

Recent reorganizations within the Army have assigned primary responsibility for managing technology base research to the Army Research Laboratory (ARL). ORNL is developing several cooperative programs in fundamental research with ARL, including work in advanced materials, microelectronics, robotics, and advanced computing.

Work will continue on a major research initiative concerning the aging of materials, electronics, and other components in Army weapon systems. A major materials study will continue for the Armament, Chemical and Munitions Command, and related work will continue in advanced composites, ceramics, carbon/carbon bonding, intermetallics, and related technologies. Research in material processing and analysis techniques, including mathematical and computational modeling of crack propagation, will continue. These projects are designed to develop advanced armor and shielding as well as lighter-weight components for increased mobility of weapon systems and vehicles. Advanced shielding materials and processing concepts, such as microwave sintering of ceramics for armor, will be evaluated for ARPA, the Tank Automotive Command, the Ballistics Research Laboratory, and other agencies. In addition, work continues on advanced materials for reentry vehicles and space applications for the Strategic Defense Command.

Initiatives in advanced instrumentation and robotics and intelligent systems technology, including advanced robotics concepts for ARL, Fort Belvoir Research and Development Center, and other related agencies, continue to expand. New programs to defend against high-energy agile laser technology for the battlefield are also planned. Stand-off detection of agents using advanced laser techniques will be studied. Communication and information technology for battlefield integration will be evaluated.

A team of researchers in the ORNL Robotics and Process Systems Division is working to develop an automatic system for reloading ammunition into battle tanks. Automated reloading technology will increase crew safety, reduce the size of armor support crews, and increase the battlefield availability of armored fighting vehicles by increasing loading speed. The Future Armor Rearm System (FARS), sponsored by the Army's Project Manager for Ammunition Logistics, consists of a tracked, armored frame and a specialized unit that houses systems for storing ammunition and transferring it into a tank. Development of FARS has required a total integrated systems approach, using a broad range of ORNL expertise and capabilities, particularly in remote

systems, telerobotics, and advanced automation. The technology was successfully demonstrated during FY 1993.

ORNL continues to support major environmental assessments, including assisting the Army's program manager for chemical demilitarization to prepare site-specific environmental impact statements for the disposal of chemical agents and munitions in U.S. locations and one non-U.S. location (Johnston Island in the Pacific Ocean). ORNL also assists the Army in the development of emergency response plans for installations that store chemical agents and munitions. For the DOD Installation Restoration Program (IRP), ORNL is assisting the Army's Environmental Agency in analyzing scientific and regulatory issues and in defining cleanup criteria for hazardous waste sites. A number of Army waste sites throughout the country must be remediated according to Environmental Protection Agency (EPA) policies and guidelines. ORNL scientists are using their knowledge of the EPA's regulations and risk assessment strategies to define the necessary cleanup criteria for the Army. New environmental assessment and control technology will be developed and demonstrated; this includes topography, bioremediation, and chemical process technology for the Army Environmental Agency. New instrumentation to support the test and evaluation community will be started for Test and Evaluation Command. Advanced artillery system concepts and designs will be evaluated for the Combat Artillery School.

ORNL will expand its environmental analyses of the potential impacts of changing military operations or broader programmatic missions at specific sites. This work includes developing new environmental measurement and analytic techniques for laboratory and field applications. Work is also expanding in analytical chemistry and environmental technology to characterize chemicals (such as military fuels) and their by-products and to develop biological indicators for environmental and health assessments. A major new initiative has begun to plan, demonstrate, and evaluate pollution prevention technologies. The initiative includes evaluation of environmentally safe materials as well as hazardous waste minimization technologies.

R&D for the Army in operations research and transportation systems, energy conservation, energy security, fuels research, and advanced engineering command continues. Included among these projects are the development of telecommunications systems prototypes and a model for the coordination of routing and scheduling military convoys over the U.S. highway system. Research to develop regional economic assessment decision support systems for recruiting and for force structure analysis for the National Guard Bureau and the Army Reserve and Recruiting Command is expected to grow moderately over the planning period. ORNL is providing analytical techniques for force structure and mobilization planning and related civilian missions.

The Army's Chemical Research, Development, and Engineering Center is supporting efforts to refine techniques for the detection of biological and chemical materials in the air. Various combinations of lasers, optical fibers, and advanced spectroscopic techniques are being used to support the Army's efforts to develop instruments that can be used on future battlefields.

Technical assistance is also being provided to the Army Environmental Hygiene Agency to prepare Material Safety Data Sheets for incorporation into DOD's Hazardous Material Information System. In addition, toxicity summaries and Applicable or Relevant and Appropriate Requirements (ARAR) documents are developed for the Army.

Work in power systems and materials for Fort Belvoir has included a project to demonstrate that motor-generator sets procured by the Army could meet all design requirements while significantly reducing the total weight if major portions of the sets were fabricated from commercially available composites. Demonstration prototypes were tested against the design requirements and then made available to the vendors as examples of technology to be exploited in future procurements.

Work also continues for the Picatinny Arsenal to develop, evaluate, and test new designs for compulsators and power systems for electromagnetic and advanced gun systems.

In a program for the Test Measurement Device Activity, ORNL is developing procurement acceptance procedures for state-of-the-art instrumentation. Typically, the Army develops a performance specification for the next-generation electronic component; however, with a state-of-the-

art component, there is no conventional test method to verify that it meets the performance specification. ORNL has developed instrumentation and procedures to be used in "First Article Acceptance Testing" to verify that these state-of-the-art instruments meet the performance specification.

Navy and Marine Corps • ORNL conducts research for the Navy and Marine Corps in engineering systems, instrumentation, data systems, reliability and maintenance, materials R&D, fuel supply and use, diesel testing, human factors engineering, energy conservation, and waste disposal. This research has diverse applications and has contributed significantly to many Navy and Marine Corps programs located at a variety of laboratories and institutions.

ORNL's Navy Mobility Fuels Forecasting System has been used to estimate the availability and quality of Navy fuels for various petroleum supply scenarios and to analyze the impacts of democratization of Eastern Europe and related events. In research cosponsored by the Navy and DOE, the forecasting system is now being used to evaluate the fuel production effects of the U.S. Clean Air Act.

ORNL plays an important role in instrumentation and engineering R&D for the Carderock Division–Naval Surface Warfare Center (CD-NSWC). The CD-NSWC is the Navy's primary research, development, test, and evaluation center for naval vehicles. Two primary areas of interest to the CD-NSWC are ship and submarine silencing and methods to design and test high-strength hulls and components. ORNL assists the CD-NSWC in the design and development of R&D instrumentation systems for experimental models of proposed submarine designs, the development of new ship and submarine designs, and support for the current fleet. ORNL also continues to evaluate new technologies for the Navy's advanced submarine R&D program.

ORNL provides a variety of design, engineering, and development support for the Coastal Systems Station in the areas of submarine countermeasures, amphibious warfare, naval special warfare, and mines and mine countermeasures. ORNL is also providing electronics development and human factors engineering support for the Naval Medical Research Institute in areas related to divers and diving. ORNL research for the Naval Air Systems Command involves the design and evaluation of advanced part-task trainers for Navy missile systems. Issues related to the ability to ensure high levels of training effectiveness and the relationship between trainer fidelity and human performance are key concerns involved with appropriate mental models and subsequently with effective trainer interface design.

For other Navy facilities, R&D continues on instrumentation and equipment reliability and maintenance; methods are being explored to determine optimal times for preventive maintenance. ORNL research also involves productive base analysis that addresses the capability of U.S. industry to produce defense material in a time of war. Research continues on new techniques to modernize naval systems, especially in the areas of logistics, mobilization planning and modeling, command and control, marine telecommunications, environmental technology, computer-aided instruction, and robotics and intelligent systems. Other R&D efforts include electronic component design cost-effectiveness, life-cycle analysis, and prototype development for the Naval Sea Logistics Center, a computer-aided research project for the Naval Sea Systems Command. ORNL has proposed new work with the Office of Naval Research, in conjunction with the DOE Environmental Measurements Laboratory, Argonne National Laboratory, and Los Alamos National Laboratory, to characterize the extent of radioactive contamination in the Arctic basin resulting from activities of the former Soviet Union.

ORNL also provides technical assistance to the Navy Environmental Health Center in Norfolk, Virginia, by preparing Material Safety Data Sheets and hazardous material assessment reports to support the hazard communication standards of the Occupational Safety and Health Administration, the Superfund Amendment Reauthorization Act, and the right to know of the community.

ORNL has conducted several materials R&D programs for the Navy. Among them is a program to fabricate pressure hull prototypes made of polymer matrix composite for submersible vehicles.

ORNL staff are providing technical assistance to the Navy's Radon Assessment and Mitigation Program, including planning, data management, quality assurance, and quality control for the identification of structures with elevated radon concentrations at naval facilities worldwide. The key components are screening and assessment measurements, quick-response verification of radon levels, and mitigation training. Mitigation training is also being given to Air Force personnel. In a General Accounting Office review of several federal agency radon programs, the Navy's program was well received; other agencies (U.S. Postal Service, U.S. Department of Housing and Urban Development, DOE) have made inquiries to the Energy Systems Hazardous Waste Remedial Action Program about the feasibility of starting similar programs.

Air Force • For the Air Force, ORNL performs research on environmental systems, advanced materials, advanced fuels, data systems, waste management, and related areas. A major economic analysis activity supports the Air Force Civil Engineering Support Agency (AFCESA) and the Air Force's major commands. ORNL performs economic analysis and provides technical support for evaluating the use of private-sector financing to augment government funding to achieve a more rapid delivery of new facilities and services. Other support to the AFCESA includes evaluation of Air Force base energy requirements to assess whether these requirements can be met cost-effectively by increased coal consumption.

In support of IRP, ORNL is assisting the Air Force's toxicology program at Wright-Patterson Air Force Base. The IRP toxicology guide prepared by this program, covering 70 organic compounds, incorporated the latest available information on state and federal regulatory status, health hazard data, analytical techniques, environmental fate, and a wide range of toxicological data, including carcinogenicity, genotoxicity, teratogenicity, and short-term and long-term exposure effects on humans and laboratory species. In addition, all of the data were incorporated into an on-line, relational database using the ORACLE database management system. Similar information on a series of metals comprising more than 80 individual compounds or salts concern to the Air Force has been compiled, analyzed, and presented. Updates to the toxicology guide have begun. New information dissemination technology (e.g., CD-ROM and laser disk readers) will be evaluated and implemented.

For several years, the ORNL Applied Technology Division, now part of the Engineering Technology Division, has performed R&D in thermoplastic composite materials and managed the Thermoplastics for Space Program for the Air Force. It is anticipated that this work will be expanded to include an Adaptive Structures Program during FY 1993.

For the Wright Research and Development Center, ORNL is performing research in multisensor integration algorithms for hypercube computer architectures. Hypercube computer architectures offer supercomputer capabilities in a small volume (which is ideally suited for robots and satellites). This research augments and complements DOE robotics multisensor integration research being carried out at ORNL. ORNL is also developing and evaluating thermoplastic materials for space applications, developing design/analysis and fabrication techniques for thick composites, and designing and evaluating foil-lined composites for cryogenic environment applications.

A major environmental R&D activity will continue to support the Air Force Environmental Impact Analysis Process in which both programmatic and site-specific analyses of Air Force actions are addressed. ORNL conducts environmental compliance assessments for various Air Force commands.

In manufacturing technologically advanced air frames, quality control is extremely important. Staff from ORNL's Health Sciences Research Division are identifying pertinent spectroscopic properties of advanced composite materials. The results of this work will be applied by the Air Force to the development of nondestructive tests that can be used during manufacture.

ORNL performs site characterizations and performance assessments for potentially contaminated sites and for new facilities at DOD installations (Air Force, Air National Guard, Navy,

Army) with the primary objective of assessing contamination problems. ORNL works to apply innovative techniques, to identify and pursue research needs based on observations at numerous field sites, and to communicate lessons learned and research applications in the technical literature.

A project is under way to use technology developed in the magnetic fusion program for removing paint from aircraft. This project, which involves the use of cryogenic pellets in an application that is similar to sandblasting, is being carried out for the Warner Robins Air Logistics Center.

Military Transportation • One of the most successful WFO programmatic areas at ORNL involves R&D for the DOD transportation agencies. To coordinate this work with other Laboratory research in transportation systems, ORNL management created the Center for Transportation Analysis, which blends complementary work for DOE, the Department of Transportation, and the various defense transportation agencies. The Center links such WFO sponsors as the Federal Aviation Administration, the Federal Highway Administration (FHWA), and the three components of USTRANSCOM—the Air Mobility Command (AMC) [formerly the Military Airlift Command (MAC)], the Military Sealift Command (MSC), and the Military Traffic Management Command (MTMC). The Center's staff has won wide recognition throughout the military for its contributions to increasing the efficiency of both peacetime and wartime moves. Most work to date has been in the area of scheduling and transportation analysis for AMC, MSC, and MTMC.

Center staff are now engaged in development of a comprehensive system that will help manage AMC's transportation missions. This system, the AMC Deployment Analysis System (ADANS), is an airlift planning and scheduling tool that helps AMC to schedule routine missions so that shipping demands can be met at minimum cost. First used successfully in Operation Desert Storm, ADANS continues to be used for response to worldwide contingency and humanitarian efforts, such as famine relief in Somalia. ORNL researchers are currently focusing on integration of air refueling scheduling in ADANS.

A microcomputer-based system for estimating strategic cargo and personnel flows of an overseas deployment was developed at ORNL and used by USTRANSCOM's emergency operations center during the Persian Gulf deployment. Earlier work by ORNL, the Energy Systems Computing and Telecommunications Services organization, and University of Tennessee personnel produced a sophisticated sealift scheduler for the MSC and a continental U.S. traffic management prototype for the MTMC. The sealift scheduler is designed so that the same algorithm can be used in the MSC's large IBM mainframe and USTRANSCOM's microcomputer-based flow estimator. The MTMC deployment traffic management prototype is used to analyze transportation mode assignments and route military traffic to airfields and seaports during an overseas deployment.

Staff at the Center for Transportation Analysis are also working with the MTMC to design and develop an integrated cargo database. This database will provide worldwide visibility of international cargo that passes through common-user ports. The database, various processing modules, and communications controls are being cooperatively developed by ORNL and MTMC personnel at four geographically separated locations. An innovative architectural design, developed specifically for these system requirements, provides a centralized data repository and processing hubs located close to the ocean ports that provide cargo status data. Designed around open-systems, client-server technology, the system allows processing to occur at the ports, the database, or the hubs. The Center for Transportation Analysis has a lead role in the system's overall analysis, design, documentation, integration, and testing. In FY 1993, the center is responsible for designing a menu capability that controls the construction of queries and optimizes response times.

Defense Nuclear Agency • ORNL performs research for the Defense Nuclear Agency in support of the Human Response Program. The human factor in the military nuclear environment is addressed through models and databases that predict the human response in all nuclear threat situations. Research is carried out through expert integration of state-of-the-art radiation transport and human response data. ORNL is satisfying the conditions for this program as defined under the DOD Qualified Research Requirements documents through a multiphase plan that includes definition and

analytic validation of the initial and protracted radiation environments, shielding calculations for tactical armored vehicles, and extensive comparison of existing and new methods to assess radiation impacts on military vehicles and human beings. The Defense Nuclear Agency also supports research at ORNL to define more accurately the effects of nuclear weapon radiation on the populations of Hiroshima and Nagasaki. In addition, it supports the Radiation Shielding Information Center to provide an information analysis center for Defense Nuclear Agency contractors involved in radiation transport R&D.

A portable, lightweight system to weigh vehicles while they are in motion has been developed under the sponsorship of the Defense Nuclear Agency. A proof-of-principle weigh-in-motion system was developed with DOE funding and used as a demonstration unit for the Defense Nuclear Agency. The Defense Nuclear Agency has since sponsored further development of the system to meet its requirements of 1% accuracy over a range of 0.5 to 30 metric tons. Several private companies have expressed interest in the system, which uses an array of fiber-optic sensors and switches, an interface for converting optical signals to electronic data, a battery pack, and a computer control system.

Ballistic Missile Defense Organization • Work is currently being performed on neutral particle beams, lightweight power and energy storage systems, optical components, survivability and shielding, flywheels, parallel computing and sensor integration, and lightweight structures made from high-temperature materials. The level of effort for the coming years will be determined by national policy.

The Survivable Optics MODIL is a major initiative in this area. This program will continue to examine and to integrate optical technologies into an overall fabrication process and to examine the broad scope of the manufacturing system as opposed to the singular development of manufacturing subsystems. It will provide the integrated technology that, if implemented by private industry, would achieve the stated optical component goals.

Two major ongoing programs are the optics development and shielding programs. Under the direction of the Army Strategic Defense Command, expertise and facilities available within Energy Systems for mirror and lens fabrication, telescope fabrication and snap-together assembly, radiation testing, and optical characterization are applied to the development of radiation-hardened, passive optical components. These components are of interest for ballistic missile defense and potentially to other areas within DOD and NASA. Energy Systems capabilities are also applied to developing shields for protecting satellites against high-kinetic-energy particles, high-energy lasers, and particle beams as well as natural and man-made radiation.

ORNL staff members have taken an advisory role for the federal government as part of the Technical Advisory Group for the Superconducting Magnetic Energy Storage Project.

Other U.S. Department of Defense Agencies • ORNL has initiated a project for ARPA on artificial intelligence for transportation planning research. Work will expand on R&D in advanced parallel computing for the Worldwide Military Command and Control Information Systems Program Office.

National Aeronautics and Space Administration

In FY 1993, ORNL was designated NASA's eighth Earth Observing System (EOS) Distributed Active Archive Center (DAAC). The functional area of concern for the ORNL DAAC is biogeochemical dynamics, a topic that has been studied extensively in ORNL's Environmental Sciences Division to explore its relationship to ecological models and global change. The DAAC will gather, assure the quality of, document, archive, and distribute data and data products in support of NASA's field projects and other global change research and policy-making efforts. It should enhance the Laboratory's capabilities to delineate critical biogeochemical processes in support of the national Global Change Research Program. The DAAC also complements DOE's Atmospheric Radiation Measurement archive activity at ORNL, ensuring a close tie between the two largest single

components of the Global Change Research Program. ORNL is also developing proposals to support NASA's component of the Global Change Research Program related to the response of water resources to climate change and issues of landscape scale.

NASA funding is anticipated for ORNL to design and implement major components of global vegetation dynamic models, to contribute to the formation of comprehensive earth system models, and to consult in the design of remote-sensing satellites from the standpoint of model data requirements and application of vegetation models to interpret satellite imagery. We anticipate new initiatives addressing impacts of climate change on natural resources; support of joint research in mathematical, statistical, and computational methods is expected from NASA's global change program. ORNL is also working with the Tennessee Valley Authority (TVA) and NASA to propose new work that would investigate the effects of climate change on water resources in the southeastern United States.

ORNL researchers are working with NASA to simulate conditions in space and aboard the space shuttle. High-frequency electromagnetic coils are used to levitate and melt samples for metallurgical experiments that investigate the effects of undercooling on crystal structure. The equipment has been successfully demonstrated in vacuum on the ground, and work is under way to qualify the process in zero gravity and to improve its efficiency.

NASA's initiative to establish a continuing human presence on the moon and Mars creates an opportunity for ORNL to support the development of reliable space nuclear power systems for both electrical and propulsion applications. Work in this area is under way. NASA also provides funding to the Robotics and Intelligent Systems Program for research on robotic and human-system interface technology for space missions.

ORNL is developing advanced high-temperature thermal storage technology using metallic phase-change media for advanced solar dynamic power systems. The effort includes modeling of system thermal performance and prototype development and testing. This work is an extension of thermal energy storage work being performed for DOE.

For the NASA–Lewis Research Center, ORNL has undertaken the conceptual design of a number of superconducting magnet systems, providing the amount of conductor and approximate cost for each system and scaling rules that can be used to estimate the size and cost of other solenoidal magnets of the type designed. Increasing support for this work is expected.

U.S. Department of Health and Human Services

The U.S. Department of Health and Human Services (HHS) supports research, literature evaluation, analysis, and database development in carcinogenesis, genetics, and toxicology. Funding from this source is expected to remain reasonably constant. The majority of HHS funding is from the National Institutes of Health (NIH); some funding is from the U.S. Food and Drug Administration.

ORNL provides guidance for the Agency for Toxic Substances and Disease Registry (ATSDR) on the performance of health assessments at hazardous waste sites on the Superfund List. Methodologies are being developed to predict acute and chronic health effects resulting from exposure to hazardous chemicals. In addition, ORNL provides technical expertise in updating and evaluating ATSDR's Toxicological Profiles; recommends chemical candidates for further testing to fill information gaps in health risk assessment; evaluates the effectiveness of Toxicological Profiles; and is developing a geographical information system, for use in evaluating health effects at Superfund sites, and regulatory information databases.

The National Cancer Institute (NCI) is supporting a study of neoplastic changes in tracheal epithelial cells. A major change is in the response to the factors that induce cell differentiation; in this context, the role of transforming growth factor β (TGF-β) is being investigated. The response to this growth factor, and therefore its influence, changes as cells progress from preneoplasia to neoplasia. The NCI also supports the analysis of epidermal growth factor (EGF)/EGF receptor interactions and their mitogenic consequences as illuminated by studies with specifically modified EGF variants.

Environmental exposures usually involve more than one carcinogen or toxic agent, yet little is known about the interactions of such agents. The development of a flowthrough tracheal implant system has made it possible, with NCI funding, to study the effects on tracheal cells of mixture of agents and sequential exposures at the molecular, cellular, and tissue levels.

The National Institute for Environmental Health Sciences (NIEHS) supports large projects on genetic and developmental effects of chemicals. The mechanisms by which gene mutation and chromosome aberration are induced in germ cells are investigated, and the molecular and cytogenetic nature of the genetic lesions is analyzed. Also studied are organismic effects in first-generation offspring of chemically exposed mice.

With support from NIEHS, the hypothesis that gene transposition is an important part of the mechanism of carcinogens induced by environmental agents is being tested. A mouse-model system is being used to investigate whether the mouse chromosomal long terminal repeats, containing retroviral gene elements, are capable of initiating genetic transposition following the genotoxic injury of the cell.

The National Institute for Child Health and Human Development (NICHHD) supports a project to generate transgenic lines of mice by injection of DNA into fertilized eggs. Researchers in ORNL's Biology Division have generated a transgenic mouse line that contains the human gene for sickle cell disease. This model animal has significant potential for use in the investigation of a widespread disease and for the assessment of possible therapies.

The National Center for Human Genome Research (NCHGR) supports saturation mutagenesis (using a point-mutation inducer) within defined segments of the mouse genome for physical/functional mapping. The NCHGR also supports production of the *Human Genome News* in collaboration with DOE's Office of Health and Environmental Research.

The National Institute of Aging, NICHHD, and, indirectly, the National Institute of Alcoholism and Alcohol Abuse support projects for the cryopreservation of embryos of mice with distinctive genetic properties.

Continuing studies on the crystallographic analysis of nucleosome structure, with the goal of 3-Å resolution, are partially supported by the National Institute of General Medical Sciences.

U.S. Environmental Protection Agency

ORNL's EPA program addresses numerous health, environmental, and economic problems and issues, including the ecological effects of global change, toxic effects of pollutants associated with energy production processes and waste disposal, methods for environmental monitoring and assessment, assessment of environmental impacts of biomass energy technologies, and the development of remote sensing techniques for characterizing the subsurface environment. Health and environmental risk analysis and epidemiological studies continue to be important components of this work. ORNL is also involved in the development of biomarkers for assessing exposure to and effects of environmental contaminants and is continuing its evaluation of the economic viability of recycling solid waste, with emphasis on plastics recycling. In addition, work is under way to evaluate economic incentive programs that might be used to promote additional recycling, source reduction of solid waste, and use of biomass energy.

The EPA is also supporting research at ORNL to evaluate the impact of municipal waste incineration on human exposure to pollutants through the terrestrial food chain. ORNL is developing a computerized model of the terrestrial food chain to aid in this analysis.

The EPA is supporting experiments to investigate the high incidence of congenital defects produced when fertilized mouse eggs are exposed to certain chemicals. The mechanisms by which these defects are produced may include interference with gene expression in the conceptus.

Biologically based assessment of the human risk from exposure to hazardous chemicals involves a series of decisions concerning unresolved issues in risk assessment. ORNL staff members, with support from the EPA and the National Science Foundation, are developing biologically based

pharmacokinetic and pharmacodynamic methodologies to evaluate the scientific bases of these decisions. Pharmacokinetic models predict chemical transport and metabolism across routes of administration, across species, and through temporal variations; pharmacodynamic models relate genetic mutation frequencies and cell-turnover dynamics to the epidemiology of cancer in animal and human populations.

The EPA's Office of Emergency and Remedial Response is supporting research at ORNL to evaluate the development and implementation of nationally consistent cleanup criteria for sites contaminated with hazardous wastes. This work includes a critical review of international approaches, development of a database of experiments with establishment of criteria at contaminated sites in the United States, classification of sites into common contaminant scenarios, and probabilistic transport and fate modeling of each scenario. Cumulative risk distribution functions will be produced, representing the variability in risk across contaminated sites resulting from the use of a nationally consistent goal vs a site-specific assessment. Alternatives for establishing uniform remediation goals will be developed and compared to the site-specific approach by comparing the cumulative distribution functions.

The EPA is supporting ORNL in organizing a national symposium and preparing a white paper on measurement and interpretation of volatile organic compounds (VOCs) in soils. The symposium has been organized by ORNL, the University of Wisconsin, the EPA, DOE, the U.S. Army Toxic and Hazardous Materials Agency, and the American Petroleum Institute in cooperation with the Geological Society of America. This work will (1) explore the foundation of the conventional VOC measurement and interpretation process and (2) examine results from research and practice that have advanced the understanding of this process, including sample collection, preservation, and preanalytical handling; on site and in situ measurement techniques; and data analysis and interpretation. The symposium will provide a forum to develop consensus on the state of the art, to make recommendations for current practice, and to identify critical research needs.

In a 3-year, $500,000 joint cooperative research project involving the EPA and private industry, unique capabilities and facilities are used to test building envelope thermal materials and systems at ORNL's Buildings Technology Center. Products are being tested to evaluate their effectiveness in reducing heat gains and losses through low-sloped commercial roofs. New materials are being identified and tested to replace materials produced with chlorofluorocarbons (CFCs). Other cooperative projects with the EPA include a study of advanced thermodynamic cycles for refrigerator/freezers using alternative refrigerants and a laboratory and field study of foam insulation with non-CFC blowing agents.

ORNL scientists are also assisting the EPA with the development and evaluation of advanced spectroscopic methods for analyzing chemical pollutants.

ORNL scientists are evaluating and analyzing the literature and will prepare a variety of health and environmental summary and assessment reports for the EPA. These include

- chemical hazard information profiles,
- reportable-quantity documents for carcinogenicity and chronic toxicity,
- health and environmental effects documents,
- reference dose/concentration profiles for oral and inhalation exposures, and
- reports on reduced uncertainty in risk assessment methodology development (less than lifetime risk assessment).

ORNL is also collaborating with EPA, industry, and universities to prepare in-depth health effect evaluations on exposure to electromagnetic fields and diesel engine emissions.

Database development activities for the EPA are expected to increase; see Sect. 10, "Information Resource Management," for descriptions of the Chemical Unit Record Estimates (CURE) database, under development for the EPA Office of Health and Environmental Assessment, and the Gene-Tox database and Environmental Mutagen Information Center (EMIC) files. A novel technique developed in association with the EPA's Health Effects Research Laboratory allows for the computer generation of graphic displays of experimental data on single chemicals or groups of

chemicals. In one of the largest efforts of its kind, toxicity data on more than 22,000 unique chemicals are being used for finding patterns among chemical and biological data. ORNL scientists are also collaborating with EPA to develop a new approach to handling health risk assessment for federal facilities.

Acidic deposition research and assessment activities are expected to increase slightly during FY 1993. The major emphasis is on the effects of acidic precipitation on forest and aquatic systems and on ion mobility in soils. New emphasis will be placed on cost-benefit analyses of emissions controls mandated by the Clean Air Act. Continued support of the EPA's critical loads research program is also anticipated.

ORNL will continue its research and analysis support to the EPA's Environmental Monitoring and Assessment Program in the areas of ecological indicators, landscape pattern analysis, biological markers, environmental risk, and technical integration and assessment. We hope to continue with follow-on activities after completing the development of an environmental assessment sourcebook for the EPA Office of Federal Activities.

ORNL is also performing research on techniques for quantifying risks of toxic chemicals on fish populations and analyzing technical issues related to the development of guidelines for ecological risk assessments.

EPA support is expected in four important analyses dealing with ecological impacts resulting from global climate change. In approaching the problem of predicting biosphere response to global change, the program will (1) assemble relevant databases on the increase in trace gases in the atmosphere; (2) perform critical experiments to determine the direct and indirect effects of pollutants on tree species; (3) synthesize data, models, and experimental results to produce regional predictions of the direct and indirect effects of global change; and (4) simulate the global response of vegetation to climatic effects. ORNL anticipates new work with the EPA on the effects of anthropogenic stressors on habitat and biological diversity research. Habitat changes in the southeastern United States are the focus of one initiative. Another area of research is the effects of climate change and land use modifications on tropical ecosystem fauna.

Research in advanced data systems continues for the EPA's Office of Planning, Budget, and Program Management. The aim is to develop computer analysis capabilities that will allow the EPA to better formulate environmental regulatory policy and analyze groundwater contamination. ORNL is also participating in the development of the EPA's climate change initiative and will continue to expand its work for the Office of Emergency Management Systems in support of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

ORNL provides technical support to EPA Region IV programs such as restoration and remediation of sites in the southeastern United States on the National Priorities List. Work continues to evaluate the adequacy of existing emergency response systems near chemical plants and to develop software for managing chemical emergencies. In addition, research in physiological pharmacokinetic models, which aids in low-dose extrapolation, continues for the EPA's Carcinogen Assessment Group. ORNL is also analyzing environmental issues and opinions for the Office of the Administrator.

National Science Foundation

Because of its unique position as a leader in systems and theoretical ecology, ORNL plays a strong role in these fields and works closely with various universities. The National Science Foundation (NSF) has provided support for a study of nutrient cycling, ecosystem metabolism, and ecosystem resilience. This project involves development and experimental testing of models that relate nutrient cycling in stream ecosystems to certain physical and biological characteristics of streams in order to predict the response of stream ecosystems to disturbance. ORNL will continue to explore its potential contributions to the planned interagency (U.S. Department of the Interior–NSF–

DOE) Continental Drilling Program. Another research effort sponsored by the NSF involves development of a fiber-optic-based fluoroimmunosensor, an instrument using monoclonal antibodies and laser-induced luminescence for the detection of trace levels of biological species in body fluids. Additional research is expected to include mathematical and statistical methods for data analysis.

ORNL is providing technical assistance to the Division of Polar Programs in its effort to evaluate the environmental impacts of U.S. activities implementing minimal-impact goals in Antarctica under the National Environmental Protection Act, the Antarctic Treaty, and the Madrid Protocol. ORNL assisted NSF in preparing a programmatic environmental impact statement on the U.S. program and will continue to support NSF in implementing minimal-impact goals and preparing site- and project-specific environmental impact assessments. Emphasis is being placed on waste and fuel management, logistic support facilities, sensitive resources, and global concerns for the Antarctic environment.

ORNL expects level funding from the NSF in the next several years.

Federal Emergency Management Agency

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

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

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

U.S. Agency for International Development

ORNL assistance to the U.S. Agency for International Development (AID) is currently focused on technical assistance to projects in Central America, R&D and technical assistance to the U.S.–Asia Environmental Partnership, and technical assistance to the Renewable Energy Applications and Training Project of AID's Office of Energy and Infrastructure, Bureau of Research and Development. Activities in Central America include serving as technical monitor and project evaluator for a large multiyear rural electrification project of AID's Regional Office for Central American Programs and carrying out analyses, technical assistance, and project monitoring and evaluation support for environmental and natural resource activities of AID's field mission in

Guatemala. Assistance to USAEP emphasizes potentials for expanding markets for U.S. energy and environmental technologies in Asia through adaptation to better fit Asian market conditions.

ORNL is also assisting the U.S. country studies program in support of the Intergovernmental Panel on Climate Change, which is led by the Department of State and supported by DOE, EPA, and AID.

U.S. Department of Transportation

ORNL's Center for Transportation Analysis, which receives funds from the U.S. Department of Transportation (DOT), covers all transportation modes; particular attention is given to highway transportation, which accounts for more than 73% of the energy used on travel in the United States. ORNL is assisting the Federal Highway Administration (FHWA), and will assist the recently established 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 vehicle highway systems.

ORNL is developing procedures to estimate the private sector's contribution to the nation's highway infrastructure and assisting the FHWA in studying the relationship between truck accidents, highway geometric design, and truck performance characteristics. Results from this study will guide the design of highways to more safely accommodate heavier trucks. ORNL is also developing methods to reduce statistical bias in two 1987 nationwide truck surveys: the Truck Inventory and Use Survey and the Nationwide Truck Activity and Commodity Survey.

Research in highway network design is exploring possible alternative routing options for trucks. Improved routing will allow more economical transport of goods and reduce the potential for considerable damage to the highway system. More effective highway network design and routing policies can also benefit DOE by providing better options for the shipment of spent nuclear fuel. ORNL is helping the FHWA to examine future federal network design options, ensure national network connectivity, and anticipate future traffic growth.

Innovative log-linear modeling of vehicle miles of travel by vehicle types, roadway class, season, and state provides the FHWA with a means of generating travel forecasts from large, sparse matrices containing large numbers of zero-valued cells. Research on the relationship between methods of forecasting vehicle miles of travel and fuel use at the national level offers insights that are useful to both DOE and FHWA policy and planning staffs. ORNL is also increasingly involved in helping the FHWA select and apply sampling methods for the collection and analysis of truck freight transportation information.

To support these analytical efforts, and in cooperation with agencies within DOE and DOD, ORNL has been the leader in the development of an extensive national highway network database that contains roadway lengths, traffic capacities, and other statistically and operationally useful planning characteristics for about 400,000 miles of highway. Workstation versions of this database are being developed for use in a variety of graphically enhanced highway research applications.

ORNL will be increasingly involved in providing the FHWA with technical support on research projects that study highway safety from the viewpoint of geometric design, highway systems operation, and hazardous materials transport. Application of expert-system methodologies to traffic simulation is emerging as a research area.

For a National Highway Network Evaluation and Design Project, ORNL will generate a number of candidate 2020 national highway networks. Goals such as traveler mobility, equity, intercity trade, and connectivity for national security reasons will be translated into network design/selection criteria.

Working with the FHWA, ORNL is developing real-time traffic monitoring and routing models. Real-time traffic analysis is a rapidly growing area of work dealing with the increasingly important issue of the energy and environmental effects of vehicle traffic on our cities.

ORNL is also supporting the FHWA's expanding research on intelligent vehicle and highway systems; funding of $4 million was provided in FY 1993. This area of research holds promise for reducing congestion and highway accidents through advanced electronic traffic monitoring and control systems and through intelligent vehicles and guideways.

In addition, the Federal Aviation Administration is developing a modeling and analysis facility, the National Airsystem Management Facility, for the development of advanced systems for airport and airways management. ORNL is well suited to provide research support to this new facility and to other operations research and simulation efforts in the Federal Aviation Administration by virtue of its extensive R&D work for AMC.

U.S. Department of Commerce

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

ORNL provides planning, technical coordination, and implementation of regional projects designed to employ the C-CAP protocols. Each project will involve collaboration with a university, state government agency, or other regional organization. Technology transfer will be a key technical requirement in the collaborative efforts. Candidate regional projects include Galveston Bay, the Louisiana coast, Tampa Bay, the South Carolina coast, the North Carolina coast, Chesapeake Bay, the Rhode Island coast, the St. Croix estuary, San Francisco Bay, the Columbia River estuary, the Alaska coast, and portions of the Great Lakes. ORNL will process satellite images and other data in support of these regional projects, develop improved methods and techniques for measuring spectral change, and develop new methods and techniques appropriate to the assessment of accuracy in large spatial databases involving change over time.

In January 1992, the NOAA National Climatic Data Center (NCDC) commenced the U.S.S.R. Surface Baseline Climate Data Sets Project as part of the NOAA Climate and Global Change Program. The purposes of the project were to (1) prepare high-quality, well-documented databases of Soviet Union climatologies, (2) make these databases accessible to the research community, and (3) make provisions for the permanent archival of these databases. The Carbon Dioxide Information Analysis Center (CDIAC) agreed to support NCDC in this effort. In the initial phase of this work, CDIAC performed quality assurance, inventory, and documentation of two databases: a 223-station database of daily temperature and precipitation measurements, and a 223-station database of measurements made every three hours, including temperature and precipitation. CDIAC also reformatted these databases and provided them to NCDC in the NCDC standard element file format. In the second phase of this work, CDIAC will assist NCDC in expanding both data sets. The daily data set will be expanded by incorporating data from 1884 to 1986 for variables other than temperature and precipitation (e.g., snow, cloud cover, and atmospheric pressure). The every-three-hour data sets will be expanded by incorporating a 1936–1965 synoptic data set of measurements made every six hours, thereby expanding the data by moving the starting date from 1966 to 1936.

Other Federal Agencies

ORNL provides technical support to a variety of other federal agencies, including the U.S. Department of Agriculture (USDA), the U.S. Department of State, and other agencies.

The Laboratory anticipates collaborative work with the USDA, including the Agricultural Research Service, the U.S. Forest Service, and USDA research laboratories.

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

ORNL is assisting TVA in an assessment of the potential for biomass energy within the TVA power system. Support is provided to the Bureau of Labor Statistics in artificial intelligence systems to provide estimates of consumer prices index and survey automation. Work is anticipated in support of the Office of National Drug Control Policy and its various support agencies.

ORNL provides support in environmental management of water resources to several other federal agencies. For example, ORNL staff serve as technical advisors to the Bureau of Indian Affairs and the U.S. Army Corps of Engineers on environmental issues such as hydropower impacts on fish and wildlife and instream flow policies.

Nonfederal Organizations

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

Electric Power Research Institute

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

A recent book by ORNL authors synthesizes the results of the EPRI-funded Integrated Forest Study, which analyzed the effects of atmospheric deposition on forest nutrient cycling. Work is continuing in the Compensation Mechanisms in Fish Population Program, which includes model R&D on the impacts of hydroelectric projects, such as instream flow requirements and water quality alterations. An anticipated activity with EPRI is the evaluation of forest response to elevated CO_2 and global climate change. A major effort initiated in 1992 on atmosphere/surface exchange of mercury is directed at understanding and modeling the deposition and emission of vapor-phase compounds of mercury. In addition, a project on the role of vegetation in remediating waste sites has begun.

EPRI continues to fund research at ORNL in areas related to the efficient use of electric energy. An efficiency research project now under way is testing full-size ice storage systems for cooling commercial buildings. Also under way are projects to develop diagnostic procedures for detecting toxic by-products of power circuit breaker gases and to develop CFC replacement fluids in commercial chiller units. EPRI cooperation and support are expected for major DOE programs at ORNL in areas of health effects of electric and magnetic fields, high-voltage direct current transmission, and real-time control of transmission and distribution systems.

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

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

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

ORNL is researching a portable operating system for power plant controllers. This project is proposed as an exploratory research project for EPRI involving technology acquisition that may have a significant economic impact on control system software development and implementation. The project goal is the development and demonstration of a portable, real-time operating system compatible with the UNIX operating system. The results will indicate methods for minimizing or eliminating the difficulties and expenses of transferring software between processors when computer hardware is replaced.

Assessment of the role of volatile salts such as ammonium chloride in the carryover of corrosive species in steam generator circuits is limited by the lack of data and predictive models. Experimental data are being obtained at ORNL and incorporated into broader thermodynamic models.

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

American Petroleum Institute

The American Petroleum Institute supports research at ORNL to evaluate the pharmacokinetics and pharmacodynamics of benzene in humans. The work is intended to provide a better estimate of the risk of developing leukemia following exposure to low doses of benzene.

ORNL also provides support in the area of global climate change by developing inventories of greenhouse gas emissions associated with petroleum product combustion. The inventories will focus on energy consumption and fugitive gas losses through production, refining, and distribution.

Joint Institute for Energy and Environment

The Joint Institute for Energy and Environment (JIEE) is an organizational entity established by ORNL, the Tennessee Valley Authority, and the University of Tennessee to conduct research and other collaborative activities on critical topics related to energy and the environment. Under the JIEE, skills and facilities from theoretical research through laboratory explorations to full-scale demonstration projects are combined with policy and social science expertise to address research topics such as the science and policy implications of climate change; the role of environmental education, training and technology transfer in global economic development; domestic and international energy and environmental policy; and energy production and conservation.

Other Nonfederal Organizations

Private industry has joined with ORNL through cooperative R&D agreements, licensing agreements, user agreements, and other mechanisms, as discussed in Sect. 7, "Technology Transfer and Science and Mathematics Education." ORNL also interacts with many other nonfederal entities, including

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

Laboratory Directed R&D Program

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

The LDRD Program comprises two major activities: the Seed Money Fund and the Director's R&D Fund. The Seed Money Fund is a continuation of the original ORNL Seed Money Program initiated in 1974; the Director's R&D Fund was added in 1983. The approved FY 1993 budget was $10.2 million; $2.5 million was allocated for the Seed Money Fund, and $7.5 million was allocated for the Director's R&D Fund. The other $200,000 was placed in an LDRD capital equipment fund, which was used for the first time by ORNL in FY 1993. All of the capital equipment funds were spent on FY 1993 Director's R&D Fund projects. The total budget authorized for LDRD amounts to less than 2% of the total operating budget for ORNL. Table 5.28 lists projected funding for FY 1992–FY 1995.

Table 5.28
Laboratory Directed R&D funding by fiscal year
($ in millions—BA)

	1992[a]	1993	1994[b]	1995[b]
Total funding	10.0	10.2	10.2	10.2

[a]$9 million allocated.
[b]Estimated.

Proposals for Seed Money Fund projects are accepted directly from the Laboratory's scientific and technical staff at any time of the year, are peer reviewed, and are selected for funding with the assistance of a Proposal Review Committee composed of representative scientific and technical staff. Each of these nominally one-year projects is generally funded at less than $120,000; the average funding level in FY 1992 was about $62,000.

Director's R&D Fund proposals are solicited from the scientific and technical staff in June of each year and are reviewed through line management; most are selected by the Laboratory's R&D Strategic Planning Committee, which is composed of senior Laboratory managers and research staff members. These projects may continue for a maximum of three years, although many have durations of one to two years. The average FY 1992 budget for these projects was $190,000; total budgets for three-year projects average about $472,000. From 5 to 10% of the Director's R&D Fund is allocated individually by the Laboratory associate directors.

Unlike the Seed Money Fund, the Director's R&D Fund is targeted at a specific list of research topics that are considered important to the future of the Laboratory. These topics are selected annually by the ORNL R&D Strategic Planning Committee. The committee chooses a "focus" area, under which projects are given top priority for funding, and several "target" areas, from which proposals are also considered but with lower priority than those from the focus area. Exceptionally strong proposals from other areas are also considered.

For FY 1994, the focus area is high-performance computing. The target areas, in alphabetical order, are advanced manufacturing, advanced materials and processing, biotechnology, environmental technology, and transportation.

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

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

- *Accomplishments of the Oak Ridge National Laboratory Seed Money Program,* DOE/ER-0274, U.S. DOE, 1986;
- *A Review of the Oak Ridge National Laboratory Seed Money Program,* DOE/ER-0319, U.S. DOE, 1987; and
- *A Review of the Exploratory Research and Development Programs at the Five Multiprogram Energy Laboratories,* DOE/ER-0361, U.S. DOE, 1988.

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

6 • Environment, Safety, and Health

ORNL is committed to conducting operations and R&D in a manner that protects the environment, the public, and Laboratory staff while allowing the conduct of world-class research in a competitive manner. In attaining this goal, ORNL takes an integrated approach to environmental, safety, and health (ES&H) matters.

The Laboratory's ES&H mission, objectives, and strategies are documented in the *ORNL Environmental, Safety & Health Management Plan* (ORNL-6702, December 1991). Every employee is responsible for ensuring that his or her work is carried out in compliance with ES&H requirements. Self-assessment against high standards of ES&H compliance is becoming an essential part of the ORNL culture. A broad program supports the line organizations in addressing ES&H issues and provides internal appraisals and audits to ensure that requirements are met.

The Laboratory states its ES&H mission as follows:

> The ES&H mission of ORNL is to conduct operations and R&D in a manner that protects the environment, staff, and public while allowing ORNL to continue to carry out world-class research in a competitive manner. We must achieve and maintain compliance with environmental, safety, and health laws and regulations. We intend to excel in our efforts by building an exemplary record of accomplishment in protecting the health and safety of our people and the public. We shall also be exemplary in protecting the environment from effects of present and future operations and restoring the environment from past operations. We want to become known as one of the best research laboratories in the United States in taking the lead in developing and executing innovative and cost-effective environmental, safety, and health actions.

ES&H Goals and Objectives

The Laboratory's ES&H goals and objectives are presented in Table 6.1. These goals and objectives are based to a large extent on goals and objectives developed by Energy Systems and presented in the *Energy Systems Environmental, Safety and Health Strategic Plan* (ES/ESH/INT-2, Martin Marietta Energy Systems, Inc., June 1991). Items that are specific to ORNL are listed first and designated with an "O" in their numbering. Periodic reviews of all goals and objectives are carried out to determine appropriateness, scheduling, and progress; a comprehensive review is currently under way.

Table 6.1
ORNL ES&H goals and objectives

ORNL-specific objectives

O-1 Pursue adequate funding for ES&H activities.
O-2 Develop a process to balance and prioritize R&D and ES&H aspects of work.

Health and safety objectives

Compliance and excellence

H-1 Provide a safe work environment.
Measure: reduce industrial and radiation accidents to 20% of industry standard.
H-2 Achieve and maintain compliance with health and safety rules.
Measure: By 1994, have no valid continuing complaints
H-3 Conduct health and safety such that ORNL is a benchmark for other contractors by 1996.
H-4 Implement an asbestos management program that will eliminate asbestos exposure through removal, containment, and elimination of use.
H-5 Use Conduct of Operations, Maintenance, etc., to pursue excellence with emphasis on procedures, efficiency, and empowerment.
H-6 Improve ORNL understanding of customer concerns regarding safety and health.
H-7 Set up mechanisms for health and safety staff to work with line organizations in interpretation and implementation of programs.
H-8 Maintain an effective nuclear criticality safety program.

Personnel and public

H-9 Maintain sufficient technical personnel to support health and safety programs.
H-10 Enhance the effectiveness of the emergency preparedness program.
H-11 Ensure that senior management addresses health and safety concerns of neighbors within 24 h.

Management systems

H-12 Institute better integrated and more consistent systems in medical services, personnel health, industrial hygiene, industrial safety, and radiation protection.
H-13 Perfect the self-assessment process for health and safety activities.
H-14 Incorporate health and safety concerns into work with other DOE contractors and subcontractors.
H-15 Establish and maintain a system for identifying needs for policies and procedures based on DOE orders and other regulations.

Cost and productivity

H-16 Apply Total Quality Management to health and safety activities.
H-17 Reduce the types and quantities of hazardous materials.
H-18 Reduce the number of external and internal audits to the minimum necessary.

Technology

H-19 Structure work environments to minimize exposures and provide training and equipment for workers to be fully informed of hazards.

Facilities

H-20 Update and obtain approvals for all required safety documentation. Through Conduct of Operations and configuration management, provide an integrated, compliant, and change-protected documentation set.

Table 6.1
(continued)

H-21 By 1998, complete the phased Safety Analysis Report Upgrade Program for all facilities.

H-22 Implement a graded approach to Conduct of Operations, Maintenance, and Radiation Protection. Implement Radiological Control (RADCON) Manual requirements in accordance with implementation plan submitted to DOE. Ensure that requirements are met and cost-effective activities are maintained.

Environmental objectives

Compliance and excellence

E-1 Comply with environmental laws, regulations, and agreements.

E-2 Strive to achieve a minimum-discharge operation.

E-3 By 2019, eliminate or reduce to prescribed levels all environmental risks from past operations through cleanup or containment.

E-5 Reduce solid waste disposal to 50% of the 1991 level by 1995 and to 25% of the 1991 level by 2000.

E-6 Institute the ability to dispose of radioactive waste, either off site or on site, by 1996.

Personnel and public

E-7 Maintain sufficient technical personnel to support environmental compliance programs.

E-8 Set up mechanisms for environmental compliance staff to work with line organizations in interpretation and implementation of programs.

E-9 Enlist and empower all personnel in protecting the environment and in conservation and pollution protection of their workplace.

E-10 Ensure that senior management addresses environmental concerns of neighbors within 24 h.

Management systems

E-11 Help in establishing an Energy Systems–wide environmental record-keeping system.

E-12 Maintain facility conformance with requirements through an ES&H Regulatory Compliance Assessment Program.

E-13 Incorporate environmental concerns into the Energy Systems procurement process.

E-14 Incorporate environmental concerns into work with other DOE contractors and subcontractors.

E-15 Establish and maintain a system for identifying needs for policies and procedures based on DOE orders and other regulations.

E-16 Work with DOE to establish mutually accepted risk and vulnerability prioritization for environmental projects.

Cost and productivity

E-17 Apply Total Quality Management to environmental activities.

E-18 Shorten average time for each phase of environmental restoration projects.

Technology

E-19 Become the best DOE laboratory in R&D, testing, demonstration, and transfer of new science and technologies in the environmental concerns area.

E-20 Become the DOE model contractor for use of appropriate new technology in remediation or restoration projects.

Table 6.1 (continued)	
E-21	Continue to serve as a resource to DOE by providing leadership in environmental restoration and waste management.
Facilities	
E-22	Include planning for environmental compliance and pollution prevention in new projects.
E-23	Minimize environmental impacts from deteriorating, inactive facilities.
E-24	Successfully implement and operate all radioactive and mixed waste management facilities.

Current Conditions

The diversity of ORNL's programs and the complement of unique research facilities that support these programs present equally diverse ES&H challenges. Operations in the past, although they may have been conducted in accordance with the standards of the time, have left behind "legacies" that require extensive restoration activities. Additional challenges are imposed by unfavorable conditions on the Oak Ridge reservation, such as high seasonal rainfall, the shallow groundwater table, high levels of calcium and magnesium in the groundwater, and the complex hydrogeology of the site.

The ORNL ES&H program is designed to promote compliance with DOE orders, Energy Systems plans and policies, the findings of internal and external audits, and all applicable federal, state, and local regulations. An extensive program of environmental restoration and waste management is carried out with the aim of resolving historical problems derived from past operations and ensuring compliance with all applicable guidelines and regulations.

Most of the ES&H issues that ORNL faces fall into five main categories. These categories are derived from the Energy Systems plan, the Tiger Team root causes, and ORNL management judgment. The issues are internally and externally driven and represent both threats to the mission and opportunities to be exploited. They are presented here in a logical sequence (not in order of importance).

ES&H Expectations and Regulatory Requirements

The Laboratory works to comply with federal, state, and local statutes; environmental laws and regulations; and DOE orders and directives. These include, but are not limited to, the Clean Water Act (CWA); the Clean Air Act (CAA); the Resource Conservation and Recovery Act (RCRA); the Toxic Substances Control Act (TSCA); the Comprehensive Environmental Response, Compensation, and Liability Act/Superfund Amendments and Reauthorization Act (CERCLA/SARA), the National Environmental Policy Act (NEPA), and other environment-related acts, directives, and guidelines.

In particular, ORNL strives to meet the environmental goals articulated by the Office of Energy Research: preventing and eliminating damage to the environment, attaining beneficial uses of the environment without degradation, reducing the risks of undesirable or unintended consequences, and achieving productive harmony with the environment.

ORNL Variances from Current Expectations

Over the last 50 years, significant advances in scientific and technical knowledge have been made at ORNL, many of them in the area of nuclear science and engineering. The attainment of this knowledge has created several major present-day problems.

Many older facilities, which represented the state of the art in their time, still exist and fall below today's standards for safety and health. Also, during research, development, and pilot production, some facilities and surrounding areas became contaminated with radioactive material or hazardous chemicals. Much of the work, including the waste management practices, was thought adequate or even advanced at the time. However, the resulting waste and environmental legacies do not meet current standards. These legacies will require major amounts of restoration activities for the foreseeable future.

"Cultural inertia" at ORNL produced a resistance to change in ES&H matters, especially in areas of administration and documentation (which have less-observable immediate benefits). ORNL management recognized the need for change and has led the effort to institute a new attitude throughout the organization. While the new culture has not been completely institutionalized, much progress has been made. ORNL's goal is to comply with ES&H requirements as rapidly as it is possible for us to do so.

Limited Resources

At the same time that DOE was rapidly increasing its ES&H requirements, it was faced with overall budgets that did not keep pace with these requirements. Budgets were prepared and approved long before the new ES&H requirements were set and the associated costs were known. Researchers did not include sufficient funds for ES&H in their proposals. When needs increased, overhead rates on research accounts were raised or research funds were redirected to pay for the increased requirements, or necessary actions were deferred.

These strategies have had several negative effects. There has been a net decline in support for basic science at ORNL. Often, funds have not been budgeted for facility maintenance or for complete cleanup afterwards. As a result, facilities have deteriorated and require costly repairs and upgrades for continued use. Also, there are many "orphan facilities" that have no current sponsor but for various reasons have not been accepted into the surplus facilities program. In many areas, funding has not been sufficient to upgrade ORNL's ES&H compliance posture. The support cost is beyond the means of ongoing research activities or overhead. Many ES&H categories still require a substantial infusion to bring them to a point of compliance where ordinary programmatic and overhead charges will suffice to maintain the compliance status.

It has been difficult in the past to find sufficient numbers of high-quality personnel with critical ES&H skills. This has been a national problem resulting from the recent explosion in regulatory requirements. The Laboratory now has a full complement of personnel with these skills but still faces this problem when personnel must be replaced because of attrition.

Management Systems

Management systems, while evolving to meet the increased ES&H emphasis, need further improvement. Key weaknesses are in the areas of diversity of operational practices, inefficient corrective action management, unclear roles and responsibilities in ES&H, and immature institutional self-assessment. These weaknesses have been recognized by senior ORNL management and are being addressed.

The relative autonomy of divisions, programs, and other research groups is appropriate for a multifaceted research organization but does not correspond to the organizational structure with which

DOE and regulatory groups are most familiar. Auditors have frequently noted that responses are excellent in some parts of the Laboratory, but not as good in others. The goal is to improve the consistency of response across the Laboratory without imposing inappropriate controls on research.

When resources are insufficient to do everything that is necessary, a system must be established to ensure that the most important activities are addressed and corrected. Priorities are set and used to determine the relative importance between activities. Further work is necessary to provide efficient and timely communication of requirements, assign responsibilities, and monitor performance.

The ES&H central staff at the Laboratory (1) provides assistance and guidance to line staff who must organize their research and other functions to comply with ES&H requirements and (2) conducts internal appraisals and audits to ensure that the requirements are met. Managing these functions to avoid conflicts of interest while maintaining a common understanding of the requirements is difficult with limited resources. In the past, responsibilities for compliance with ES&H regulations were generally assumed by the ES&H organization because of the organization's expertise in the area and the willingness of line management to transfer that responsibility. Line managers are now taking on a larger role in the ES&H aspects of their work.

Senior management is striving to make self-assessment against high standards of ES&H compliance a part of the ORNL culture. This process is incorporating division-level identification of problems and proposals for correction. Laboratory-wide integration of the process to identify generic and cross-division issues is being pursued. Components must be in keeping with DOE directives on the subject and must include provisions for independent assessment as well. The process is being implemented at ORNL, and its integration into the operations of the Laboratory is being stressed by senior management.

Leadership in ES&H Matters

The Laboratory possesses special expertise in ES&H matters. Several of ORNL's divisions (Environmental Sciences, Health and Safety Research, Analytical Chemistry) perform world-class research in various environmental fields, as described in Sect. 5, "Scientific and Technical Programs." The safety and health programs and Conduct of Operations of other divisions have become models for other DOE organizations. Within the DOE system, the ORNL Research Reactors Division is a leader in safe and productive research reactor operation. The Environmental Technology Development organization conducts research on improvements in the handling of waste and the remediation and restoration of waste sites. Overall, ORNL is considered one of the best run of the DOE laboratories in the ES&H arena.

ES&H Policies, Organization, and Management

It is the policy of ORNL to strive for excellence and to conduct all operations in a manner that ensures protection of our people, the public, and the environment. Operations are conducted effectively, in compliance with applicable federal and state laws, orders, and regulations, and in a manner consistent with the associated hazard. Processes are systematically evaluated to ensure compliance and to appropriately reduce risks; these evaluations include continuing self-assessments and prioritization of efforts to ensure the most effective use of resources.

At ORNL, the Laboratory Director has the primary responsibility for implementing the ES&H program according to requirements and for developing and implementing ES&H program procedures and instructions according to ES&H directives. The research divisions of the Laboratory, as line organizations, are responsible for ES&H activities within their areas. Each division manager is

responsible for ensuring that division staff members are properly trained for the functions that they perform, ensuring that division facilities are safe and in compliance, and addressing problems or issues that arise.

Within a division, ES&H offices are held by division staff members. These positions, which can be full time or part time, include safety officer, radiation control officer, environmental protection officer, and training coordinator. Other, more specialized positions may be established as needed; examples include hazard communications coordinator and waste minimization coordinator. Some ORNL divisions consolidate these offices into a single section within the division that is staffed by full-time personnel to provide line-managed support for ES&H.

Support to the line organizations is provided by central ES&H and operations organizations. For example, in most divisions oversight for and assistance with quality assurance are provided by a quality assurance specialist assigned to the division by the Office of Quality Programs and Inspection. The Environment, Safety, Health, and Quality Coordination Committee provides communication and coordination of tasks among organizations involved in these activities, ensuring top-level management oversight of this area.

Five offices carry out assignments in compliance and operational improvement. The offices' areas of responsibility are environmental compliance and documentation, operational readiness and facility safety, radiation protection, safety and heath protection, and quality programs and inspection.

ES&H functions related to general plant operations are carried out by the ORNL Health Division and the Waste Management and Remedial Action Division. Some aspects of the work of the Plant and Equipment Division and the Training and Development Department within the Human Resources Division are also related to ES&H activities.

Management and performance indicators, published monthly, receive a wide distribution to Laboratory management and are also distributed to Energy Systems and the DOE Site Office. The indicators cover a wide range of subjects such as personnel exposures, corrective and preventive maintenance, waste management issues, environmental (RCRA, NEPA) issues, audit and corrective action status, occurrence reporting and report status, and an assortment of administrative and safety concerns. The indicators also include trending, lessons learned, and alerts as well as milestone and Total Quality Management (TQM) implementation status. The data are used by managers to identify positive and negative trends.

ES&H Plans and Initiatives

Strategies have been developed for addressing each of the ORNL ES&H objectives. These strategies detail the actions necessary to achieve the objectives. In addition, numerous program, compliance, and response plans provide guidance in other ES&H activities that are necessary for the continued operation of the Laboratory but do not relate specifically to the stated ES&H goals and objectives. Figure 6.1 shows the relationships between the major types of plans. Typically information flows downward, but upward flow of information is also possible. A significant amount of crossflow of information takes place between corrective action plans, program plans, and compliance plans.

Table 6.2 provides the estimated cost of safety and health for ORNL based on the Laboratory's input to the DOE Safety and Health Five-Year Plan. These estimates were developed through analysis of the expected needs at the Laboratory. Actual funding for future years has not been determined. All activities associated with these costs have been ranked using the DOE Safety and Health Risk Priority Matrix, and the results have been submitted to DOE-ORO for transfer to the responsible primary secretarial offices. In future years, budgets are to be determined based on the input of the Five-Year Plan, the relative priority of individual activities, and the availability of funds.

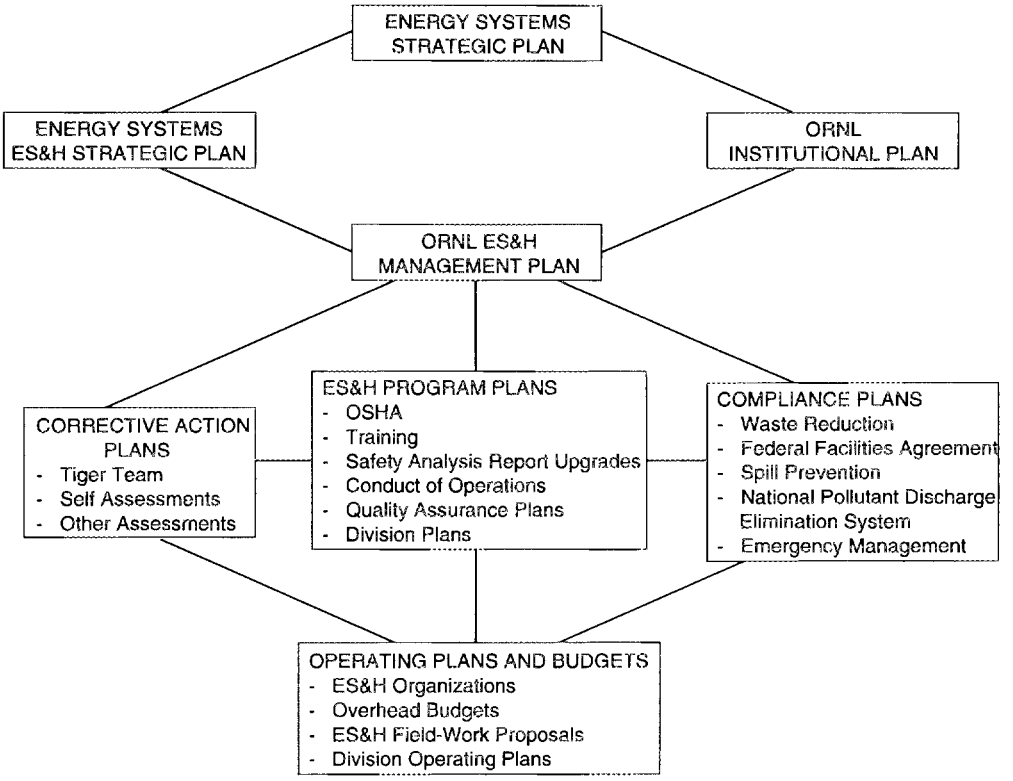

Figure 6.1
Relationships among ES&H planning documents.

Table 6.3 provides an estimate of funding requirements for corrective actions associated with the ORNL Tiger Team Assessment. Because many corrective actions are performed as part of an individual's ordinary duties, it is difficult to completely capture all associated costs. This is especially true for actions funded indirectly through overhead rather than as specific requests to DOE. A significant amount of funding is still required to complete the actions in response to the Tiger Team.

The role of the Waste Reduction Program (WRP) is to provide coordination and technical guidance to divisions in the reduction of waste, as well as the planning and reporting required by state and federal laws and DOE orders. Additionally, waste streams that are common to several divisions are evaluated by the WRP. The WRP addresses all waste streams generated at ORNL: sanitary/industrial, radioactive, hazardous, and mixed. The Pollution Prevention Awareness Program is also administered by the WRP and is designed to heighten employee awareness of the waste reduction initiative and to emphasize the value of each individual's contribution toward reducing waste. Table 6.4 provides the funding requirements for ORNL's Waste Minimization Plan.

ORNL is a leader among DOE facilities in the application of the NEPA process for its planning activities. A system has been developed to help Laboratory staff flag projects for review to determine the applicability of NEPA. Preliminary screening identifies whether projects may qualify for a categorical exclusion or may require more detailed environmental assessments. Project managers are kept informed of the status of their projects, and a dedicated staff prepares and tracks the necessary documentation. DOE personnel make the determination of the proper classification of projects and must approve all projects, but the efforts of the ORNL staff facilitate the actions of DOE.

Table 6.2
Safety and Health Plan funding by fiscal year[a]
($ in thousands)

	1993	1994	1995	1996	1997	1998	1999
Indirect	51,210	55,623	54,679	64,497	68,104	70,395	70,702
Operating[b]							
Defense Programs	1,460	1,130	990	980	920	870	906
Energy Research	45,082	89,163	98,250	83,696	78,587	78,799	71,543
Nuclear Energy	3,110	3,291	3,449	3,605	2,962	3,057	3,174
Total operating	49,652	93,584	102,689	88,281	82,469	82,726	75,623
Capital equipment							
Energy Research	6,045	21,227	24,436	14,745	13,485	13,055	12,900
Total capital equipment	6,045	21,227	24,436	14,745	13,485	13,055	12,900
GPP[c]							
Energy Research	400	3,852	1,960	2,813	500	200	0
Total GPP	400	3,852	1,960	2,813	500	200	0
Line item							
Defense Programs	0	0	0	9,750	20,500	9,900	0
Energy Research	1,525	4,829	7,195	24,204	14,875	25,324	0
Total line items	1,525	4,829	7,195	33,954	35,375	35,224	0
Total Safety & Health	108,832	179,115	190,959	204,290	199,933	201,600	159,225

[a]Does not include cost from Energy Systems central organizations distributed to ORNL.
[b]Includes division administration as a direct operating expense.
[c]General plant project.

The serious shortage of adequate space at ORNL includes space for ES&H personnel. Some relief is proposed through the construction of a 50,000-ft^2 ES&H Compliance and Training Building. This building will house about 200 personnel from the various ES&H disciplines and will provide consolidated office space for them to interact and operate more effectively and efficiently. The 2-year project is currently scheduled to begin in 1996 and to cost $12.6 million.

Environmental Restoration and Waste Management Activities

Environmental restoration and waste management activities at ORNL are the line responsibility of the Central Environmental Restoration Division and Energy Systems Waste Management Organization of the Energy Systems Environmental Restoration and Waste Management Programs. The Waste Management and Remedial Action Division at ORNL handles waste management activities and surplus facilities management aspects of environmental restoration. Site characterization and remediation aspects of environmental restoration are managed by the Central Environmental Restoration Program, which serves as the focal point for these activities at all Energy Systems installations. The associate director of the Waste Management and Remedial Action Division serves as a deputy to the ORNL site manager of the Central Environmental Restoration Programs to provide integration of the waste management and environmental restoration programs. Funding levels for environmental restoration and waste management are given in Table 6.5.

Table 6.3
Tiger Team Corrective Action Plan projected funding requirements by fiscal year[a]
($ in thousands)

	1993	1994	1995	Beyond
Energy Research				
Program	11,094	9,274	740	0
GPP[b]	6,410	1,000	1,000	0
GPE[c]	200	0	0	0
Line item	25,915	21,000	27,200	9,400
ER/WM[d]				
Program	52,432	46,265	46,799	89,668
GPP	4,400	4,000	4,000	4,000
Line item	15,900	26,500	39,100	35,000
Nuclear Energy				
Program	180	400	150	50
Defense Programs				
Program	90	0	0	0
Overhead	1,905	365	123	77
Total	118,526	108,804	119,112	138,195

[a]Costs for actions are not specifically tracked within the ORNL accounting system, and funds have not been specifically requested but are included in normal budget requests. Actual funds received have not approached these amounts.
[b]General plant project.
[c]General-purpose equipment.
[d]Environmental Restoration and Waste Management.

Table 6.4
Waste Minimization Plan funding by fiscal year[a]
($ in millions—BA)

	1992	1993	1994	1995	1996	1997	1998	1999
ADS[b] 3203.2 (EW30)	0.4	1.0	2.3	1.2	1.8	1.8	2.1	2.6
ADS[b] 3252.2 (EX30)	0.7	0.6	0.7	1.2	2.0	2.3	2.4	2.6
Total	1.1	1.6	3.0	2.4	3.8	4.1	4.5	5.2

[a]Waste minimization funding is included in the Waste Management costs in Table 6.5.
[b]Activity Data Sheet.

Environmental Restoration

The ORNL environmental restoration program addresses the cleanup of environmental contamination. The program carries out three major tasks: assessment, remediation, and decontamination and decommissioning (D&D). Assessment includes identification, preliminary inspection, and characterization of a site; evaluation and selection of cleanup alternatives; and

Table 6.5
Environmental Restoration and Waste Management planned funding by fiscal year
($ in millions—BA)[a]

	1992	1993	1994	1995	1996	1997	1998	1999
EM Corrective Activities								
Operating	0.7	0.5	1.0	1.0	0.5	0.6	0.0	0.0
Capital equipment	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
Line item	2.4	15.9	18.0	26.1	6.0	0.0	0.0	0.0
Total	3.1	17.5	19.0	27.1	6.5	0.6	0.0	0.0
Environmental Restoration								
Operating	33.7	44.4	48.0	48.1	50.3	50.3	50.3	50.3
Capital equipment	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	43.6	44.4	48.0	48.1	50.3	50.3	50.3	50.3
EM Isotope Facility Shutdown[b]								
Operating	9.6	8.8	8.4	23.8	23.8	0.0	0.0	0.0
Line item	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	10.4	8.8	8.4	23.8	23.8	0.0	0.0	0.0
Waste Management								
Operating	35.3	61.0	55.7	58.0	75.5	75.9	84.3	87.4
Capital equipment	4.3	6.6	1.0	1.0	1.7	2.3	2.5	2.5
Construction	6.6	26.3	25.3	36.8	42.8	45.3	67.7	70.0
Total	46.2	93.9	82.0	95.8	120.0	123.5	154.5	159.9
Other[b]								
Operating	0.2	0.0	2.5	5.5	5.5	5.5	5.5	5.5
Capital equipment	1.4	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Construction	4.1	6.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	5.7	10.5	2.5	5.5	5.5	5.5	5.5	5.5
Total EM funding	109.0	175.1	159.9	200.3	206.1	179.9	210.3	215.7

[a]Operating BA, capital equipment, construction, and proposed construction, as noted in Table 11.5. These estimates reflect funding from Energy Systems central organizations, excluding Technology Development (EW40).

[b]Funding included in the ORNL Financial Plan.

preparation of decision documents. Remediation includes design and implementation of cleanup actions and remediation of the contents of inactive liquid low-level waste (LLLW) tanks. D&D includes assessment and cleanup activities associated with surplus facilities not governed by RCRA or CERCLA.

The environmental restoration process begins when a site requiring corrective action is identified and ends with final certification of site closure, remediation, or decommissioning activities. Between these two milestones is a structured path of program planning, site characterizations, alternatives assessments, continued surveillance and maintenance (S&M), and necessary interim corrective measures (ICMs). Some of these activities are accomplished in a relatively short time, while others may take years. The path chosen for each site depends on several variables, such as site characteristics, site-specific regulatory requirements, and resource availability.

Under past waste management practices, a wide variety of liquid and solid wastes, primarily radioactive or mixed wastes, was disposed of on site; 300 contaminated sites have been identified on the 1175-ha (2900-acre) ORNL area. Because of the large number of sites and the hydrogeologic complexity of the ORNL area, the remedial action strategy is oriented toward waste area groupings

(WAGs). The 20 WAGs in the ORNL area are defined by watersheds and contain contiguous and similar remedial action sites, each representing a distinct, small drainage area into which similar contaminants were introduced.

Activities planned for FY 1993 and FY 1994 include

- continued S&M at contaminated sites, with scoping surveys conducted at high-priority sites;
- continuation of a comprehensive site monitoring program,
- continuation of the WAG 1 phase II remedial investigation (RI),
- completion of the WAG 10 phase I RI field activities and the WAG 5 phase I RI report, and
- initiation of the phase I RI for WAGs 4 and 7.

Major closure activities include

- continued removal of contaminated debris from WAG 11 and ICM construction for the WAG 13 cesium plot ,
- completion of interim records of decision for the WAG 1 and WAG 8 ponds, WAG 11 contaminated soil, and ICMs for North and South Tank Farms,
- preliminary planning for the WAG 4 and WAG 5 seeps ICM and WAG 10 well plugging and abandonment,
- continued development of the WAG 7 pit 1 ICM,
- removal of LLLW tank contents,
- removal of one LLLW tank,
- continued studies of the treatability of tank contents,
- preliminary planning for final site remediation of WAG 1 and WAG 5, and
- completion of support facilities construction and site remediation design for WAG 6, with initiation of site remediation.

A significant number of facilities at ORNL have been declared inactive or surplus because the programs for which they were built have been completed (see Sect. 9, "Site and Facilities"). Because the potential for release of radioactivity to the environment exists, facilities will undergo D&D during the next several years. Until decommissioning is complete, facilities that contain substantial amounts of residual radioactive material must be kept under surveillance to schedule any necessary maintenance and to ensure containment. The inventory of surplus contaminated facilities includes experimental reactors, technology support facilities, hot cells, isotope processing facilities, research laboratories, and decontamination facilities. To meet the objective of adequate containment and site control, a structured program of S&M has been established to manage all activities collectively relating to surplus contaminated sites and facilities.

S&M is conducted to ensure protection of employees and the public and containment of contaminants. The annual budget for S&M is about $3 million. The objectives of the S&M Program are (1) to ensure adequate containment of residual radioactive and hazardous materials, (2) to provide safety and security controls to minimize potential hazards to on-site personnel and the general public, and (3) to cost-effectively manage surplus sites and facilities in compliance with all applicable DOE orders and ES&H regulations. These objectives are met through a structured program of periodic surveillance and site inspections, routine maintenance, and special projects beyond a routine nature to correct facility degradation or to eliminate facility-specific hazards.

ORNL has successfully decommissioned a number of facilities under the D&D Program, which began in 1976. Projects have included many small isolated jobs such as cleanup of an intermediate waste line spill site, decommissioning of a radiochemical waste system and a curium source fabrication facility, removal of research-related facilities, and the decontamination and removal of an isotope storage "garden."

The budget for decommissioning of surplus facilities is highly variable and is subject to annual reprioritization by DOE. D&D projects are implemented according to priorities set at the national level by the DOE-HQ Environmental Restoration Program. Budget requests for decommissioning of prioritized facilities at ORNL are submitted annually and included in the DOE Environmental Restoration and Waste Management (DOE-EM) Five-Year Plan. Priorities are then

ranked with facilities and sites from other DOE installations, and budgets are allocated accordingly. Projects are then implemented by the ORNL Remedial Action Program in accordance with these budget allocations. The budget for decommissioning surplus facilities is approximately $3 million in FY 1993. Subsequent annual budgets are expected to increase significantly during the planning period to keep pace with DOE's goals for site restoration. Near-term D&D projects will focus on removal of facilities in conjunction with regulatory-driven remediation of former waste management sites.

There are currently about 100 inactive or surplus facilities, including former solid waste storage areas, waste ponds, and seepage pits; radioactive waste processing and transfer facilities; research laboratories; dedicated environmental research sites; experimental reactors; and radioisotope development facilities. A facility manager has been designated for each one. The Remedial Action Section of the Waste Management and Remedial Action Division at ORNL is responsible for S&M of all areas and D&D of the contaminated facilities. Table 6.5 provides environmental restoration funding requirements.

The Isotope Facilities Shutdown Program (EX20) manages the activities required to place the ORNL isotopes production and distribution facilities in a radiologically and industrially safe condition for acceptance into DOE's Surplus Facilities Management Program (SFMP). The goal of the program is to place, by the end of FY 1996, all 16 facilities in the program in a condition such that (1) all stored radioactive materials, high-level wastes, and contaminated liquid wastes have been removed; (2) the structures and radiation monitoring systems are in a physical condition adequate to contain and to monitor any radioactive contamination in accordance with DOE Order 5480.1; (3) security systems and procedures are adequate to prevent unauthorized entry; and (4) all hazardous chemicals have been removed. The project is currently scheduled for completion by the end of FY 1996.

This program was initially funded through DOE-EM and managed by the Office of Nuclear Energy (DOE-NE). Funding and management responsibility for this program are to be transferred to EM in FY 1993. The program budget is $8.8 million in FY 1993, with estimates of $8.4 million for FY 1994, $23.8 million for FY 1995, and $23.8 million for FY 1996.

Waste Management

The waste management program at ORNL provides continuous collection, treatment, and discharge of gaseous wastes; treats 150 million gal/year of liquid radioactive waste (excluding sewage); and manages about 750,000 ft^3/year of solid radioactive, hazardous, mixed, and sanitary/industrial wastes. Major waste management activities include comprehensive coordination of waste reduction; integrated strategic and long-range planning; upgrades of existing facilities and construction of new ones; waste collection and certification; and waste treatment, storage, and disposal.

Expense funding for waste management activities in FY 1993 is about $60 million, including $1.6 million for waste minimization (see Tables 6.4 and 6.5). The corrective activities component of the expense funding provides for implementation of the Federal Facilities Agreement (FFA) requirements as they pertain to active LLLW tanks and tank systems. It also includes upgrades of the Bethel Valley and Melton Valley LLLW collection and transfer systems. Proposed line item projects include three projects for implementation of the active LLLW tank systems requirements of the FFA, one project for construction of the Melton Valley Storage Tanks Capacity Increase Project (MVST-CIP), and one project for the Process Waste Treatment Facility.

The MVST-CIP is needed because of the deferral of the transuranic (TRU) Waste Handling and Packaging Plant (WHPP). The WHPP has been designed to mobilize and treat MVST liquids and sludges, as well as newly generated LLLW, in accordance with RCRA Land Disposal Regulations, and to support the retrieval, characterization, repackaging, certification, and preparation for transport of TRU wastes (including solidified LLLW). These wastes would be transported to DOE's Waste

Isolation Pilot Plant (WIPP) in New Mexico. Current plans for TRU waste call for treatment and storage with eventual shipment to WIPP.

Out-year activities in waste management include continued operation of waste treatment, storage, and disposal facilities, with many major upgrades. Additional reservation-wide facilities for waste management will be added to promote efficiency and improved ES&H conditions. Waste reduction will continue to be emphasized.

Landlord-Funded ES&H

Indirect (overhead) funding requirements for safety and health, shown in the first row of Table 6.2, continue to increase. (Note that these values do not include environmental compliance costs of approximately $7 million.) During the preparation of the Safety and Health Five-Year Plan, managers were asked to identify how much of the FY 1993 funding requirements they actually expected to receive. This amount, $48.8 million, represents an increase of only 6.3% from 1992 and a severe shortfall from the required amount. Since the development of the Five-Year Plan, target overhead budgets that have been proposed actually reduce the overhead spending by about 5%. This has been necessary to reduce the Laboratory's overhead rate so that ORNL can remain competitive, but it exacerbates the shortfall from the required amount.

The impact of inadequate funding is continued noncompliance with regulations and DOE orders. The Laboratory risks substantial penalties for failure to comply, especially with the advent of rulemaking, which will give several DOE orders the force of law. Direct funding for ES&H compliance has been requested from DOE for the past three years through ES&H field work proposals. These proposals would allow ES&H programs to be brought up to compliance levels, after which normal overhead would suffice for maintenance of the programs.

7 • Technology Transfer and Science and Mathematics Education

Technology transfer is embodied in a wide range of ORNL activities, including cooperative research and development agreements (CRADAs) with outside institutions and consortia, user agreements, exchanges of personnel between the laboratory and universities or industry, direct work for other federal and state agencies, and subcontracted work with universities and the private sector. These efforts involve a full range of activities from theoretical research to prototyping equipment, developing products, and effecting improvements in manufacturing and processing. ORNL developments have fostered the formation of new businesses, created new jobs, and contributed to improving the balance of trade.

The focus for many ORNL technology transfer activities is provided by the Laboratory's user centers and programs. ORNL has established user centers for high-temperature materials, bioprocessing, buildings technology research, surface modification (ion implantation), and environmental research and also has a number of user facilities for basic physical research. These centers are used extensively by educational institutions and industries to carry out research and development (R&D) for educational purposes and to develop new products and processes. The strong programmatic emphasis on energy efficiency and renewable energy, fossil fuels, advanced computing, environmental science, superconductivity, and defense technologies provides a firm basis for establishing cooperative working relationships with industry.

An important factor in fulfilling the Laboratory's technology transfer mission is the knowledge transmitted by the broad science and engineering educational programs available to students and teachers at all levels. These opportunities include hands-on experiences, use of laboratory equipment and facilities for approved research activities, and on- and off-site interactions of ORNL staff members with students and teachers.

Technology Transfer Plan

Overview

ORNL's technology transfer plan supports the Department of Energy's emphasis on partnerships. Technology transfer efforts at the Laboratory are a key component of the Energy Systems technology transfer program, which focuses the resources of the Department's facilities in Oak Ridge on the technological challenges facing U.S. industry.

Vision

The ORNL technology transfer program will set the standard for technology transfer from federal laboratories.

Strategic Objectives

- The engineering and applied science infrastructure of ORNL, which has deteriorated with the decline of large programs, will be revitalized. A strong engineering and applied science base is an essential part of establishing and maintaining strong ties with industry.
- A vigorous personnel exchange program, including senior management, will be undertaken with industry to increase awareness in our staff of the industrial perspective and to acquaint industry with our capabilities.
- The development of specialized user centers having broad appeal to industry will be undertaken. Experience with the High Temperature Materials Laboratory (HTML) demonstrates that access to moderately expensive and sophisticated laboratory equipment enhances competitiveness and attracts industry to the area.
- The role of ORNL in the Regional Manufacturing Assistance Program will be expanded.
- Strategic alliances with other national laboratories, industrial consortia, and universities will be expanded to provide stronger ORNL participation in major national initiatives.
- The ORNL program will be highly innovative. Appropriate metrics will be developed and tracked to refine our approach to existing activities.
- Legal and bureaucratic barriers will be eliminated to increase university and industrial participation in the full range of our programs.

Resources and Staffing

The resources and staffing needed to implement the Laboratory's technology transfer plans are listed in Table 7.1.

Industry-Laboratory Cooperative Projects

In partnership with Energy Systems, ORNL is a leader in CRADAs and other cooperative arrangements with the private sector. Two recent developments are indicative of the Laboratory's leadership: in January 1993, the ORNL inventors of the variable-frequency microwave furnace, developed under a CRADA with Microwave Laboratories, Inc., were notified that they will receive an award from the Federal Laboratory Consortium for excellence in technology transfer, and in March 1993, ORNL and Procter & Gamble signed the Laboratory's first major CRADA in the life sciences area. The research is expected to lead to an improved understanding of tumor formation in the liver and better risk assessments of potential liver carcinogenic agents. In addition, ORNL has the lead in the area of improved processes and materials for the American Textile Partnership (AMTEX), the multilaboratory collaboration with the U.S. textile industry established by DOE's Office of Energy Research (DOE-ER) through the Energy Research Laboratory Technology Transfer Program (ER LTT). Several CRADAs in support of this partnership are expected to be initiated during the planning period.

Work is in progress at ORNL on a database for tracking Joint Work Statements (JWSs) and CRADAs to improve the efficiency of the process. This is part of a larger effort to manage the work performed under CRADAs. A management plan is being developed to define the roles, responsibilities, and management approach for monitoring the progress and performance of work in

Table 7.1
Technology transfer effort by fiscal year
Estimated expenditures and staffing for the Office of Technology Transfer[a]

	1992	1993	1994	1995	1996	1997	1998	1999
	Funding ($ in millions—BA)							
ORTA[b] activity	2.19	2.68	2.96	3.14	3.27	3.40	3.53	3.67
Patent/licensing activity	0.83	1.02	1.06	1.10	1.14	1.19	1.24	1.29
CRADA[c] funding								
Federal	4.60	18.15	20.85	23.89	24.85	25.84	26.88	27.96
Private industry	0.79	1.57	1.85	2.51	2.61	2.71	2.82	2.94
In kind[d]	4.50	17.74	20.37	23.35	24.28	25.25	26.27	27.32
Total	12.91	41.16	46.09	53.99	56.15	58.39	60.74	63.18
	Professional staffing [full-time equivalent (FTE) employees]							
ORTA activity	18.5	25.1	25.1	25.1	26.1	27.1	28.2	29.3
Patent/licensing	5.6	7.7	7.7	7.7	8.0	8.3	8.6	9.0
CRADA activity	3.0	5.0	5.0	5.0	5.2	5.4	5.6	5.8
Total	27.1	37.8	37.8	37.8	39.3	40.8	42.4	44.1

[a]Data are for the Office of Technology Transfer, Martin Marietta Energy Systems, Inc., which includes ORNL, the Oak Ridge Y-12 Plant, and the Oak Ridge K-25 Site.
[b]Office of Research and Technology Applications.
[c]Cooperative research and development agreement.
[d]Estimated.

the CRADA program. Development of this plan involves the Energy Systems Office of Technology Transfer and the principal stakeholders from all business units of Energy Systems. A draft of the plan has been submitted to DOE.

The Regional Manufacturing Assistance Program provides a mechanism for smaller manufacturers to obtain technologies from DOE's Oak Ridge facilities. This program has established a collaboration between the industrial extension services of the state of Tennessee and technologists with Energy Systems. State extension staff refer manufacturers to Energy Systems, which provides up to four free days of work by technologists to help manufacturers solve their problems. To date, more than 80 requests for assistance have been received. Of these, over 50 have been successfully handled, and more than 30 others are in various stages of completion. Assistance has ranged from short telephone conversations between the manufacturer and a technologist to company visits by technologists to understand the process and analysis of samples with sophisticated laboratory equipment. This program is expected to expand during the planning period.

At ORNL, the Office of Guest and User Interactions (OGUI) is the focal point for cooperative interactions with outside groups. OGUI functions include development and execution of CRADAs and agreements with all user facilities; implementation of guest research assignments; foreign national visit/assignment approvals for all Energy Systems facilities; provision of on- and off-site guest services; and coordination of ORNL cooperative research activities. OGUI is also responsible for oversight of projects funded by ER LTT.

User Facilities

ORNL has 10 designated user facilities designed to serve both the technical community and DOE missions by making unique facilities and equipment available to external institutions and individuals (Table 7.2). Nonproprietary research can be conducted with no cost to the user, while proprietary agreements require full cost recovery. In FY 1992, 792 scientists representing 240 institutions conducted experiments at ORNL user facilities. In 1992, 34% of the total were university scientists. Industrial scientists represent a growing segment of the user population, with 65 experimenters from 37 companies in FY 1992. A new laboratory, the Ceramic Manufacturability Center, was opened at the HTML during the past year, making a total of seven dedicated laboratories at the HTML.

In recognition of expanded facilities at the Roof Research Center, this user facility has recently been renamed the Buildings Technology Center. The new center (described in Sect. 5, "Scientific and Technical Programs") offers a combination of unique testing equipment, a wide array of mathematical modeling and computing capabilities, and a diverse expert staff.

Long-range plans for ORNL user facilities include the upgrading of the Holifield Heavy Ion Research Facility for production of radioactive ion beams. This initiative is described in Sect. 5, "Scientific and Technical Programs."

A proposal has been submitted to DOE for approval to designate the Productivity Validation Test Bed within the Engineering Technology Division as a user facility. The Productivity Validation Test Bed is associated with the Optics Manufacturing Operations Development and Integration Laboratory (MODIL). Its objective is to involve industries, universities, and other federal laboratories in the process of developing and validating new, emerging, and enabling manufacturing technologies. A high-priority objective of the Optics MODIL is to transfer manufacturing technologies to the private sector to improve the capability of the optics industry to meet the threat of foreign competition. The Optics MODIL's premise is that effective technology transfer must include hands-on training. Approval of this user facility would expand the scope of the user program and would provide additional opportunities for private sector participation in Laboratory programs.

Another ORNL user facility still in the planning stages is the Residual Stress Center. This facility is needed to quantify stress in joined materials, a major problem for national manufacturers of metal parts, ceramic-metal components, laminates, composites, or thin-film coatings.

A new user facility, the Advanced Neutron Source (ANS), which has received line-item funding for FY 1994, will be the nation's state-of-the-art research reactor. More than 1000 scientists and engineers per year are expected to use one of the more than 30 instruments that ANS will provide for experiments on materials and basic nuclear science after its startup in FY 2002. ANS is described in Sect. 4, "Summary of Major Initiatives."

During FY 1992, 42 new ORNL user agreements were signed with 15 universities, 13 international institutions, and 11 industries. Three proprietary agreements are included in this total (Table 7.3).

Guest Research

Guest scientists are a valuable component of ORNL's research staff. Their assignments, which range from two weeks to two years in length, broaden the Laboratory's base of expertise and support its mission of scientific cooperation and technology transfer. During FY 1992, the Laboratory population was augmented by 4392 guest assignments (Fig. 7.1), more than double the number of assignments 5 years ago. Of this number, 1723 were industrial guests, an increase of 22% over the number assigned in FY 1991 (Table 7.4). There were 1160 foreign national visits and assignments in FY 1992 (Fig 7.2), double the number from 5 years earlier.

Table 7.2
Experimenters at designated user facilities in FY 1992

	U.S. government laboratory[a]			University			Industry			Foreign			Total		
	Exp.[b]	Org.[c]	% of use	Exp.	Org.	% of use	Exp.	Org.	% of use	Exp.	Org.	% of use	Exp.	Org.	User days
Holifield Heavy Ion Research Facility (HHIRF)	45	5	38	78	22	57	0	0	0	14	8	5	137	35	3136
National Environmental Research Park (NERP)	95	8	57	51	16	35	8	5	8	0	0	0	154[d]	29[d]	3208[d]
High Temperature Materials Laboratory (HTML)	75	3	50	32	19	9	35	17	41	0	0	0	142	39	9015
Surface Modification and Characterization Laboratory (SMAC)	34	3	53	36	17	37	4	3	1	10	9	9	84	32	1940
Shared Research Equipment (SHaRE)	39	2	77	28	16	19	1	1	1	4	2	3	72	21	975
Neutron Scattering Research Facilities (NSRF)	31	5	52	30	16	12	7	4	2	37	19	34	105	44	2378
EN Tandem Van de Graaff accelerator	10	1	18	27	8	71	0	0	0	4	4	5	41	13	2012
Oak Ridge Electron Linear Accelerator (ORELA)	14	3	79	3	3	10	1	1	<1	4	8	11	26	11	4158
Bioprocessing Research Facility (BRF)	7	1	56	3	2	44	1	1	<1	0	0	0	11	4	230
Roof Research Center	6	2	23	5	4	37	8	5	19	1	1	21	20	12	1186
Total	356	33	50	293	123	34	65	37	7	78	47	9	792	240	28238

[a]Includes 273 ORNL users, representing 34% of use.
[b]Exp. = number of experimenters.
[c]Org. = number of organizations.
[d]Totals do not include more than 23,000 individuals who participated in the Ecological and Physical Sciences Study Center and the High School Honors Program for a total of 11,938 user days in FY 1992.

Table 7.3
User agreements executed in FY 1992[a]

Number	Name	Date approved	User type
UA-90-032	AECL Research	11/28/91	International
UA-91-018	Florida International University	06/11/92	University
UA-91-020	IBM Almaden Research Center	10/31/91	Industry
UA-91-052	University of Maryland	02/07/92	University
UA-91-065	FMC Naval Systems Division	12/06/91	Industry
UA-91-074	Mount Holyoke College	12/06/91	University
UA-91-075	Jawaharlal—India	10/16/91	International
UA-91-076	Amercom Inc.	01/09/92	Industry
UA-91-077	University of Houston	07/22/92	University
UA-91-078	Florida State University	07/29/92	University
UA-91-081	Rutherford Appleton Laboratory	11/27/91	International
UA-91-083	University of Bristol	11/21/91	International
UA-91-085	Tennessee Technological University	05/11/92	University
UA-91-087	E. I. duPont de Nemours	12/14/91	Industry
UA-91-089	University of Massachusetts	04/08/92	University
UA-91-091A	BMR Geology and Geophysics	03/18/92	International
UA-91-091B	Stevens Institute of Technology	12/12/91	University
UA-91-092	Babcock & Wilcox	08/24/92	Industry
UA-91-093	Manchester University	02/10/92	International
UA-91-095	Iowa State University	01/24/92	University
UA-91-096	AT&T Bell Laboratories	12/18/91	Industry
UA-91-097	University of Palermo	08/01/92	International
UA-92-001	Alzeta Corporation	06/04/92	Industry
UA-92-002	Concurrent Technologies Corp.	07/17/92	Industry
UA-92-010	General Electric Aircraft Engines	06/26/92	Industry
UA-92-014	Istituto ISM del CNR	03/19/92	International
UA-92-015	Tosoh SMD, Inc.	06/02/92	Industry
UA-92-016	McGill University	05/04/92	International
UA-92-019	University of Warwick	04/07/92	International
UA-92-020	University of Birmingham	03/30/92	International
UA-92-023	Torrington Company	05/19/92	Industry
UA-92-026	University of Pennsylvania	05/25/92	University
UA-92-027	Harvard University	05/01/92	University
UA-92-028	Wright State University	08/06/92	University
UA-92-029	University of Notre Dame	04/22/92	University
UA-92-032	Berea College	05/01/92	University
UA-92-052	University of Oxford	07/08/92	International
UA-92-053	University of Western Australia	07/17/92	International
UA-92-057	Washington University	09/10/92	University

[a]Does not include three proprietary user agreements.

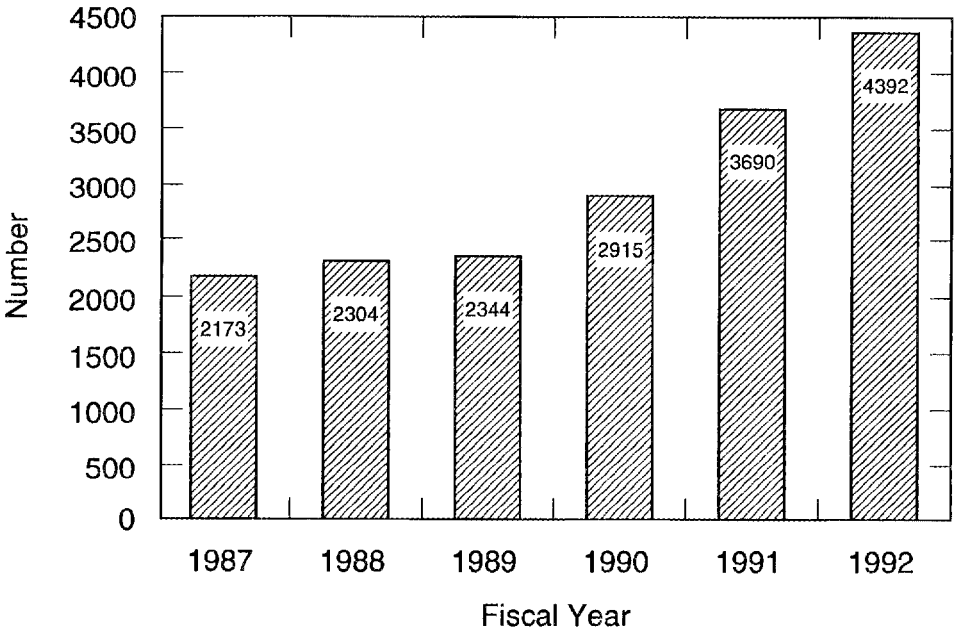

Figure 7.1
ORNL guest assignments, 1987–1992.

Table 7.4
Number of guest assignments at ORNL[a]

	1984	1985	1986	1987	1988	1989	1990	1991	1992
University	628	920	927	1378	1428	1395	1551	1696	2022
Industry	260[b]	344[b]	398[b]	617	689	736	972	1408	1723
Federal agencies	—	—	—	39	40	52	52	78	61
Foreign institutions	97	83	77	62	59	48	84	72	78
Other	49	59	191	77	88	113	256	436	508
Total	1034	1406	1633	2173	2304	2344	2915	3690	4392

[a]Guests are nonemployees who come on site to conduct research, consult, or perform other services. Users are included in the totals; e.g., in FY 1991, 674 of the 3690 guests were users.
[b]Includes Federal agencies.

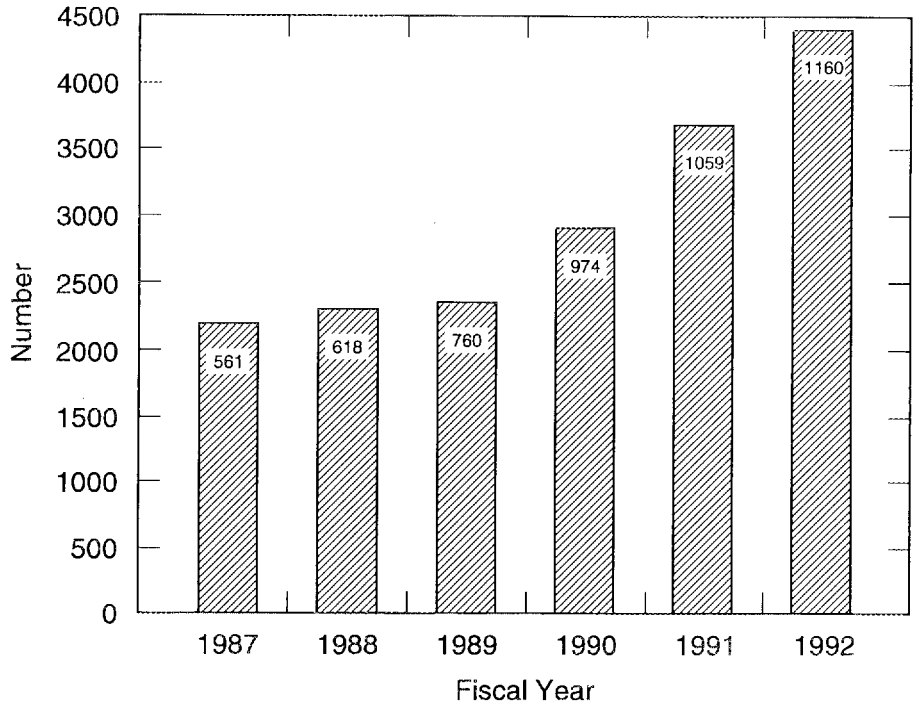

Figure 7.2
Foreign national visits and assignments to Martin Marietta Energy Systems, Inc., 1987–1992.

Cooperative Research

Since the initiation of the ORNL High Temperature Superconductivity Pilot Center program (now the High Temperature Superconductivity Technology Center for Electric Power Applications) in 1989, an increasing number of companies have recognized that cooperative partnerships with the Laboratory provide access to significant scientific resources and skills. Furthermore, the leveraging of research dollars through cost-sharing is beneficial to both parties. When Energy Systems gained the authority to enter into CRADAs in 1990, the momentum toward joint research projects increased. As of December 31, 1992, ORNL has become involved with 55 CRADAs representing commitments of $82 million, divided approximately equally between federal monies and the private sector (Table 7.5).

The AMTEX partnership engages the technical capabilities of the DOE laboratories in developing and deploying technologies that will increase the competitiveness of the textile industry, which has lost over 50,000 jobs in the last 12 years because of imports. The partnership has identified five areas of R&D focus for initial concentration: improved materials and processes; analysis, simulation, and computer integration; environmental quality and waste minimization; energy; and apparel automation. These areas will be addressed by CRADAs. ORNL has the lead in the area of improved materials and processes.

Long-Range Plans

During FY 1993, OGUI has continued its outreach programs, ranging from the dissemination of information about user facilities to the development of extensive contacts with southeastern

Table 7.5
Approved CRADAs at ORNL through August 1993

DOE program	Number	Funding ($ in thousands)			
		DOE	Funds in	In kind	Total
Energy Efficiency and Renewable Energy (EE)	27	9,281	566	7,532	17,379
Energy Research (ER)	13	3,975	450	4,592	9,017
Environmental Restoration and Waste Management (EM)	8	2,705	240	3,585	6,530
Nuclear Energy (NE)	1	1,050	1,050	0	2,100
Fossil Energy (FE)	3	50	46	84	180
Defense Programs (DP)[a]	19	32,447	50	32,087	64,584
Other	7	1,190	439	637	2,266
Total	78	50,738	2,841	48,557	102,136

[a]Includes joint projects with Oak Ridge Y-12 Plant.

universities through activities such as Deans' Day. Plans for the future involve the expansion of such efforts and the assumption of additional responsibility in facilitating technological and scientific exchange programs. The ER LTT program will be supporting other partnerships based on the AMTEX model. ORNL is exploring the possibility of developing and managing a multilaboratory collaboration focused on the aluminum industry.

Patents and Licensing

An agreement between ORNL and the Oak Ridge Institute of Science and Education (ORISE) regarding assignment of intellectual property rights arising from postdoctoral appointments has been signed by the two parties. With DOE-ORO approval, postdoctoral appointees can be assigned to CRADAs and other projects where ownership of intellectual property rights is an issue; ownership of these rights is retained by Martin Marietta Energy Systems, Inc.

Royalty income and the number of new licenses are monitored constantly and reported regularly (see Tables 7.6 and 7.7). The measure for strategic success, with respect to the technology transfer mission, is the dollar value of product sales resulting from our licensing agreements (Table 7.8). Product sales at the end of FY 1992 had reached a cumulative total of more than $60 million.

Technology Transfer Achievements

A few highlights from ORNL's technology transfer program are described here.

Blood Chemistry Analyzer

In 1989, the whole blood rotor, developed at ORNL, was licensed to Abaxis, a small California company. Since that time, Abaxis has been working to incorporate the rotor into a device now being marketed as the EPOC 2000 Point of Care Chemistry Analyzer. A drop of whole blood inserted into the center of a rotor containing very precisely measured reagents can be used to produce results on 13 to 15 different blood tests within 15 minutes.

Table 7.6
Office of Technology Transfer licenses executed in FY 1992

Licensee	Technology
Advanced Innovative Technologies, Inc.	Ceramic fiber–reinforced composites
Cast Masters, Inc.	Iron aluminides
EODT Services, Inc.	Amoeba/bacteria consortia
Finnigan MAT, Inc.	Apparatus and modules for mass spectrometer
Finnigan MAT, Inc.	Ion trap spectrometry
Glass-TEX, Inc.	Alkali-lead-iron phosphate glass
ITI MOVATS, Inc.	Check valve monitoring system
Merchant House Scientific (formerly Giles Foundation)	Manual Braille writer
Microwave Laboratories, Inc.	Variable-frequency microwave furnace
Predictive Maintenance Inspection, Inc.	Method for detecting periodic abnormalities on a periodic carrier
Sigma Electromagnetic Shielding Technologies, Inc.	Ultralight electromagnetic interference shielding
Southern California Edison Company	Check valve monitoring system
Texas Engineering Experiment Station	PCB spectral data
VacuPanel, Inc.	Measurement of vacuum in sealed thin-wall packets

Table 7.7
Licensing income and use by fiscal year[a]

	1992	1993[b]	1994[b]	1995[b]	1996[b]
Licenses					
Number of new licenses	14	18	21	25	25
License income ($ in thousands)	300	400	500	1000	1500
Use of income ($ in thousands)					
Employee awards	75	100	125	250	374
ORTA[c] office support	26	98	122	243	366
Intellectual property management	13	17	22	44	66
Cooperative research support	6	8	10	20	30
Technology maturation	120	160	200	400	600
Federal income taxes[d]	60	17	21	43	64

[a]Funds are for the Office of Technology Transfer, Martin Marietta Energy Systems, Inc.
[b]Projected.
[c]Office of Research and Technology Applications.
[d]Increased taxes in FY 1992 are due to a prior period adjustment.

In preparation for obtaining approval from the Food and Drug Administration, clinical market testing is under way for a rotor containing five reagents. Once approval is obtained, Abaxis plans to market the EPOC 2000 to physicians, clinical laboratories, hospitals, and other users.

Table 7.8
Technology transfer results by fiscal year

	1992	1993[a]	1994[a]	1995[a]	1996
Patent applications	75	78	81	84	87
Patents granted	30	43	50	67	72
Cumulative product sales ($ in millions)	62.0	75.0	89.6	104.7	120.5

[a]Projected.

Large Single Crystals of Magnesium Oxide

An ORNL development in crystal growth provided the technology that enabled a small Florida company to become the sole U.S. supplier of magnesium oxide (MgO) crystals—a specialty material that is used in optical systems and as substrates for high-temperature superconductors. A 1989 letter from Commercial Crystal Laboratories, Inc. (CCL), of Naples, Florida, to Senator Bob Graham states, Thanks to the direct efforts of Dr. Lynn Boatner, Dr. Marvin Abraham, and Mr. Homer Harmon of Oak Ridge National Laboratory, we were able to improve our manufacturing techniques and reduce our selling price 40%. This enabled us to increase our overall market share for this crystal (MgO) from an estimated 20% to an estimated 60%." Unfortunately, that picture changed between 1989 and 1991, when CCL's market share dropped to 5% after a newer technology was developed by a foreign competitor. In 1992, ORNL and CCL signed a CRADA for the development of new, commercially viable methods for the growth of MgO crystals for a variety of electronic and optical applications, thus helping the company to regain its market share and compete with foreign suppliers. The outcome of this effort will have a significant impact on CCL's future. The project is jointly funded by CCL and the ER LTT program.

The ANDROS Mark VI Robot

For applications involving hazardous environments, including radiation, temperature extremes, and chemicals, the ORNL Center for Engineering Systems Advanced Research (CESAR) has acquired an ANDROS Mark VI robot for conversion to computer control. The ANDROS robot is environmentally hardened and equipped with hardened cameras, a manipulator, and a versatile mobility system that allows it to negotiate a variety of obstacles (including climbing stairs).

The robot was built by Remotec, a local company that was started as a spin-off from ORNL about ten years ago. ANDROS is currently fully teleoperated.

The application of computer control to this robot for functions that are difficult to execute under complete remote control converts the robot into a very effective human-robot telepresence system. This provides much greater efficiency and safety in carrying out remote maintenance, inspection, and remediation in hazardous environments.

ANDROS was recently used during the investigation that followed the bombing of the World Trade Center in New York. Because it is only 43 cm (17 in.) wide, it can be used in areas with limited access—for example, to navigate the aisle of an airplane during a bomb threat.

Thin-Film Lithium Battery

Under a CRADA with the Eveready Battery Company, ORNL has developed a method of packaging rechargeable thin-film lithium batteries that are as small as shirt buttons and thinner than plastic wrap. Unlike batteries used today, which must be added to a circuit as separate components because of their large size, these thin-film batteries could be fabricated inside an integrated circuit

such as a computer memory chip. This arrangement could be used to preserve memory if a power failure occurred.

The batteries are produced using thin-film deposition techniques that are similar to those used in the semiconductor industry. This technology can easily be scaled up to produced batteries of any size and shape. The protective coating developed by ORNL effectively seals the battery against corrosion and leakage, overcoming a major technical obstacle to producing these batteries. This joint work has been funded by Eveready and the ER LTT program.

In an unprecedented move to transfer this technology to U.S. industry, a pilot plant funded by DOE's Assistant Secretary for Defense Programs has been established to assist battery manufacturers in the development of manufacturing technology for producing this product. This effort to develop a product and transfer it to the marketplace effectively combines the technical expertise of ORNL and the manufacturing skills available at the Oak Ridge Y-12 Plant.

Science/Math Education Support Programs

Education at all levels, from precollege through graduate and professional, is one of the primary missions of DOE's multiprogram national laboratories and other major facilities. Strong emphasis is placed on helping to strengthen mathematics and science education in the schools, especially in the design, development, and delivery of comprehensive and integrated programs for elementary and secondary teachers and students. Special attention is given to the following goals:

- The nation's youth from kindergarten through high school must be given a strong technical foundation on which to base future success in higher education and in science and mathematics careers.
- The nation's science and mathematics teachers must have in-depth, state-of-the-art training so they can present science and mathematics concepts in ways that spark student interest and understanding.
- Special effort must be directed toward encouraging and supporting more women, minority, disabled, and disadvantaged students in mathematics and science.

As part of this mission, DOE has given the national laboratories the designation of regional science education centers. The ORNL Science Education Center, which is part of the Laboratory's Office of Science Education and External Relations, provides a framework and an operating structure for addressing these goals.

The long-range plan for the Science Education Center incorporates both near- and long-term actions to improve (1) the overall quality of science and mathematics teaching, (2) the size and diversity of the educational pipeline in these fields, and (3) the future availability of people with scientific and technical skills. The plan's comprehensive and cooperative approach emphasizes institutional partnerships and resource sharing for mutual benefit. Key thrusts are to

- strengthen the educational pipeline, qualitatively and quantitatively, through innovative learning experiences beginning at the early elementary level;
- help to correct the historical underrepresentation of women, minorities, and people with disabilities in technical disciplines;
- broaden the impact of these educational initiatives through increased emphasis on science and mathematics teachers and students, with special attention to teacher recruitment, preparation, and professional development and enrichment;
- diversify the Laboratory's own work force to better match the changing demographics of the U.S. population; and
- expand efforts to increase the scientific and technological literacy of the general public.

Partnerships strengthen the center's focus on the national education goals and on education reform in the southeastern United States. These partnerships include cooperative efforts with other agencies [e.g., the Appalachian Regional Commission (ARC)]; state and regional schools, colleges, and universities; and the private sector. Support for these partnerships includes a major focus on computing and communications technology for educational applications. ORNL's educational initiatives include

- sponsorship of summer mathematics and science camps for middle-school-age youth (especially young women) in the area and throughout the southeastern United States;
- the Saturday Academy of Computing and Mathematics (SACAM), which draws on volunteers from the ORNL technical staff as mentors for area secondary students;
- the Oak Ridge Educational Network (OREN), which gives students and teachers access to high-performance computing capabilities, networking, and communications;
- Tennessee and southeastern U.S. involvement in the DOE-sponsored National Science Bowl;
- an annual "Women in Science" conference for high school and college students;
- classroom teaching and enrichment resources such as "The New Explorers," a DOE-sponsored public television series; and
- a multistate regional Summer Science Honors Academy sponsored by the ARC as a companion to the DOE High School Science Student Honors Program in Environmental Sciences.

School, college, and university guests are hosted by the Laboratory through a variety of mechanisms:

- R&D subcontracts;
- short-term research in the designated DOE user facilities and other resources;
- supervision of students and collaborations with faculty through research participation appointments;
- visits of technical personnel and equipment loans;
- close collaborations with universities and university consortia, appointments of teachers as research associates, and professional development workshops and student enrichment experiences; and
- learning experiences through the Ecological and Physical Sciences Study Center.

More than 35 programs—undergraduate, graduate, postgraduate, and faculty—enable students and faculty to participate in ORNL research. About half of these summer and/or academic-year appointments are administered jointly with the Science/Engineering Education Division of ORISE.

More than 100 co-op students were employed at ORNL and elsewhere in Energy Systems in FY 1992; another 400 undergraduate and graduate students, 80 postgraduates, and 70 faculty members received research participation appointments. These numbers do not include 100 college and university faculty and students who made short-term research visits under travel contracts. Visitors may perform experiments at user facilities and resources or consult with ORNL staff about common research interests.

DOE and ORNL benefit directly from the mission support gained, especially through university-level participation programs. These partnerships represent a mutually beneficial and highly cost-effective way to support ORNL's programmatic goals, while providing education and training. Students have made substantive contributions to highly successful ORNL projects. Collaborations with college and university personnel also help to fulfill the Laboratory's technology transfer objectives.

University Consortia

ORNL has active working relationships with several university consortia. A long-standing collaboration with ORISE on educational programs has been strengthened through the implementation of joint programs and joint university outreach activities. These activities include the

Southeastern Universities Research Association (SURA), established to build and manage DOE's Continuous Electron Beam Accelerator Facility at Newport News, Virginia. ORNL is a partner with ORISE and SURA in an initiative to advance materials research in the Southeast. As part of this initiative, the SURA-ORNL Summer Program in Materials Research provides a mechanism for faculty and students from SURA schools to work with ORNL staff and do materials research at the Laboratory's facilities. Graduate students may work toward either a master's degree or a Ph.D.

ORNL's Science Semester program with the Great Lakes Colleges Association/Associated Colleges of the Midwest (GLCA/ACM) is now in its third decade. The long-standing success of this program helped to strengthen the case for DOE's national Science and Engineering Research Semester (SERS) Program.

R&D Subcontracts

ORNL annually awards some 100 R&D subcontracts, valued at nearly $20 million, to more than 36 universities. These subcontracts generally sponsor research on campus but may include provisions for student internships or faculty appointments to perform research at the Laboratory. About one-third of ORNL's subcontract obligations are with the University of Tennessee at Knoxville (UTK). This includes the cost of joint appointments under the Distinguished Scientist Program and other activities carried out through the Science Alliance, a UTK/ORNL Center of Excellence supported by the state of Tennessee.

Research Collaborations

Many long-standing collaborations between ORNL and individual universities are based on mutual research interests. Most of these collaborations involve outstanding departments at these institutions and include active exchanges of students and faculty.

Among these collaborations are cooperative agreements signed in FY 1991 with the National University of Mexico and a collaborating scientist agreement with UTK. The latter agreement serves as the prototype for a widening range of interactions with academic institutions, both statewide and beyond.

ORNL is engaged in a team R&D effort for the deployment of an advanced robotic system to perform tasks hazardous to humans and/or whose execution times can be reduced if performed by automated systems. The goal of this project is to develop a generation of advanced robotic systems that can perform surveillance, maintenance, and repair tasks in nuclear facilities and other hazardous environments. This goal will be achieved through a collaboration that includes ORNL; the universities of Florida, Michigan, Tennessee, and Texas; and each institution's industrial partners. This program takes full advantage of existing resources at all of the participating institutions. Besides its own research, ORNL coordinates the overall effort, including integrated equipment tests to demonstrate overall progress.

ORNL is also a member of the Center for Neural Engineering at Tennessee State University (TSU), a historically black university in Nashville. The center represents a consortium of TSU, Meharry Medical School in Nashville, Accurate Automation Corporation in Chattanooga, and ORNL. Scientists from the Center for Engineering Systems Advanced Research (CESAR) at ORNL will provide research opportunities and information to undergraduates, graduate students, and faculty in the area of robotics and intelligent systems. The Center for Neural Engineering will help pioneer new developments in research and will share its technology with business and industry.

Through DOE's Energy Related Laboratory Equipment program, ORNL helps colleges and universities to obtain excess equipment for the cost of transportation only. The equipment ranges from small detectors to sophisticated analytical instruments and may be new, used, or in need of repair.

ORNL also works with academic institutions to enhance their educational programs and research capabilities by sharing personnel. ORNL staff members frequently give seminars at universities throughout the nation, in response to ad hoc invitations from faculty or through formal programs such as the ORISE Traveling Lecture Program and the Industrial Research Institute Visiting Scientists Program. These visits, typically lasting a day, allow students and faculty to consult extensively with the scientist and give university personnel insights into some of the cutting-edge science performed at the Laboratory. About 75 to 100 of these visits are made annually.

Many ORNL staff members are affiliated with universities on an adjunct basis to teach classes and to collaborate with faculty on research projects. Some 20 to 30 ORNL research staff members hold formal part-time adjunct appointments from UTK. Many others donate their teaching talents to UTK and other area institutions, such as Knoxville College, Tennessee Technological University, Pellissippi State Technical Community College, and Roane State Community College.

ORNL technical staff members teach short courses as part of the ORISE training programs sponsored by DOE. ORNL also provides other types of assistance to faculty, including critical review of proposals and manuscripts and organizing joint meetings and conferences.

Facilities and Equipment at ORNL

ORNL's 10 user facilities offer unique opportunities to perform experiments on state-of-the-art equipment at minimal cost. Many of these facilities are supported by separate operational funds, and users pay only their travel and housing costs.

In FY 1992, 293 university researchers performed experiments for 9,600 user days at these ORNL facilities. The largest percentage of the university-based users (26%) performed research at the Holifield Heavy Ion Research Facility. Other facilities heavily used by university researchers include the High Temperature Materials Laboratory, the Oak Ridge National Environmental Research Park, and the Surface Modification and Characterization/Collaborative Research Center. Resources available to university researchers include supercomputing capabilities, advanced electron microscopes, analytical equipment (including a Fourier transform mass spectrometer), and X-ray and neutron scattering facilities.

Precollege Programs

ORNL's precollege programs allow both students and teachers to experience directly, through "hands-on" learning opportunities, the exciting frontiers of science and the process of discovery. It is important for students to have such challenging and creative experiences as a part of their earliest encounters with science.

The ORNL-administered National Teacher Enhancement Project, sponsored by the National Science Foundation (NSF), has provided summer workshops and follow-up training during the academic year for more than 700 teachers of kindergarten through eighth grade nationally. At ORNL, up to 400 elementary and secondary teachers receive research participation appointments each year.

Educational technology is a major theme of the Laboratory's precollege outreach activities (see the description of the Educational Technology Initiative in Sect. 5, "Scientific and Technical Activities"). OREN provides access to state-of-the-art computing facilities, including DOE's National Education Supercomputer, for networking and communications as well as mathematics and science problem solving, and to a variety of federally supported information services. The education component of the High Performance Computing and Communications initiative is being carried out at ORNL through the Center for Computational Sciences (see Sect. 4, "Summary of Major Initiatives"); this includes the Adventures in Supercomputing summer workshops for teachers.

Some 125 students are selected for special on-site honors study activities on both a national and a regional basis, and another 20,000 students and teachers participate in "hands-on" learning

experiences offered year-round through ORNL's Ecological and Physical Sciences Study Center. For the fifth year in 1992, outstanding students representing all 50 states, the District of Columbia, Puerto Rico, and 7 other countries spent 2 weeks at ORNL under the DOE High School Science Student Honors Workshop Program. In this activity, which focused on environmental research, students worked in small groups under the guidance of ORNL research staff members to examine the effects of contaminants on the environment. A parallel program, begun in 1991, is the ARC-supported Summer Science Honors Academy; in FY 1993, 35 students and 14 teachers participated. The Special Honors Study Program allows exceptional high school students to receive individual instruction from staff mentors; with 8 participants in FY 1993, the program has now served 52 students. ORNL also holds a residential 10-week research participation program for students at the secondary level each summer.

Other initiatives target traditionally underrepresented groups of students in an effort to increase the pool of those who pursue further study and careers in science and engineering. Project SEED (Summer Educational Experience for the Disadvantaged), administered nationally by the American Chemical Society, encourages minority and economically disadvantaged high school students to consider careers in science and mathematics. The FY 1993 program included 18 students who held 8-week summer appointments; 12 were Hispanic students from Puerto Rico. Participants are involved in research and in weekly career orientation activities and seminars to expand their knowledge of the frontiers of science.

ORNL continues to expand the Ecological and Physical Sciences Study Center, one of its most visible and successful precollege programs. This program presents some 40 different topical study modules to visiting class-size groups and in outreach programs at schools within a 100-mile radius. Study modules, which provide opportunities for hands-on learning in both life sciences and physical sciences, are offered generally as half-day field activities and are tailored for all academic levels from early elementary through high school. The Study Center now operates year-round, including Summer Science Experience camps for middle school students and teacher workshops that transfer course content for local use. During FY 1993, more than 20,000 students and teachers participated in Study Center activities; a continuing effort is made to reach students with physical and/or sensory disabilities.

ORNL has been involved in school partnerships since 1988. The Laboratory has formally "adopted" Eastport Elementary and Vine Middle schools, which serve predominantly minority populations in Knoxville; Roane County High School in a largely rural area; and the Tennessee School for the Deaf. The DOE-sponsored Project SMART (Science/Math Action for Revitalized Teaching) has extended this program to three other East Tennessee school systems (Chattanooga City, Harriman City, and Roane County) and a total of 55 schools, both urban and rural, in a partnership that includes ORNL and ORISE.

Through these partnerships, schools have access to the Laboratory's unique skills and knowledge base, plus loans of surplus equipment, as a means of enhancing the educational experiences and opportunities for professional development available to both students and teachers. The Office of Science Education and External Relations also coordinates school partnerships involving other parts of Energy Systems, significantly extending the region-wide outreach.

Undergraduate Programs

At the university level, DOE's University Laboratory Cooperative Program (ULCP), administered through DOE-ER's Office of Science Education and Technical Information, supports research participation and training opportunities for students and faculty at ORNL through a joint effort with ORISE. Many other participants are supported directly by programmatic funds from the Laboratory's research divisions and by colleges and universities, fellowship awards, and contracts and grants.

Programs are geared to students majoring in science, mathematics, computer science, or engineering. The primary goal is to encourage the pursuit of graduate studies and careers in these disciplines. The annual "Women in Science" conference, conducted jointly with ORISE, supports efforts to increase the number of women and minorities who consider technical careers.

Participants in semester-length programs are increasing in number. Admission to the GLCA/ACM Science Semester continues to be sought after by students from the colleges of these consortia of midwestern liberal arts institutions. The "Oak Ridge experience" has a positive effect on subsequent pursuit of graduate studies and career choices in the technical fields.

The SERS Program has completed its sixth annual cycle at ORNL and five other national laboratories. At ORNL, the experience is modeled on the pioneering GLCA/ACM program. SERS attracts students from colleges and universities across the United States, with about 70 participants each year at ORNL.

The Student Research Participation Program offers 10-week summer appointments in ORNL research divisions for 30 or more undergraduates. Other programs providing extended appointments for undergraduates include the Professional Internship Program and the Technology Internship Program. The latter program was developed to enhance training for technical students at 2-year colleges and has been the source of several permanent technical employees at ORNL.

Summer educational programs make it possible for students to work in the ORNL research laboratories for about 10 weeks. These programs are open to most students and are a popular avenue for many who wish to do research at a national laboratory. One of these, the Service Academies Research Associates Program, provides summer research opportunities for rising seniors from the U.S. military academies.

Graduate and Postgraduate Programs

Prethesis master's degree and Ph.D. candidates, other students performing thesis or dissertation research, and postdoctoral applicants are appointed to ORNL through various graduate and postgraduate education programs. The goal is to enhance the educational experiences of these students by providing opportunities to work in laboratory situations and with advanced equipment not readily available at their schools. A major consideration in the selection of these students is the compatibility of their backgrounds and interests with research projects in ORNL divisions. Postdoctoral and graduate (thesis research) participants must be accepted by ORNL's Graduate Fellow Selection Panel or through national panels established by DOE's Office of Health and Environmental Research (DOE-OHER) and Office of Fusion Energy (DOE-OFE). DOE-OHER sponsors two programs in parallel with the Alexander Hollaender Distinguished Postdoctoral Fellowships, now in their sixth year. The newer programs support work in the areas of human genome research and global environmental change. In addition, ORNL makes several postdoctoral appointments annually through its own Eugene P. Wigner postdoctoral fellowships, administered by the Human Resources Division, and participates in the DOE Distinguished Postdoctoral Research Program.

ORNL's own Postdoctoral Research Program, recently expanded, has the goals of

- advancing scientific and technical training in areas of critical national need,
- providing research opportunities for outstanding scientists and engineers,
- promoting the influx of new ideas and skills into the laboratory, and
- enhancing interactions with the wider academic and research communities.

Postdoctoral appointees become integral members of ORNL R&D teams, gain exposure to current national issues in science and technology, have an opportunity to share and exchange innovative ideas and techniques, make significant contributions to ORNL programs, and enhance their own professional development.

Graduate degree candidates, performing research for theses or dissertations, work under the supervision of a graduate committee composed of representatives from their school and from ORNL.

Students who have not yet completed the required course work can participate in the Professional Internship Program for graduate students or the Graduate Student Research Participation Program. These programs are structured to provide prethesis research experiences for students aspiring to degree candidacy. Many of these participants are selected later for the higher level programs.

Faculty Programs

Faculty research appointments at ORNL are made through various programs for terms of a few days, 10 weeks to 3 months in the summer, or longer for sabbaticals. These appointments include short-term visits, collaborative or student-faculty team projects, shared research equipment, work at a user facility and programs that emphasize underrepresented minority participation, such as those developed specifically for faculty members of historically black colleges and universities (HBCUs) and other minority educational institutions (MEIs).

Goals for faculty research participation programs prioritize technology transfer, the university's energy-related research interests, and enhancement of curriculum offerings. Faculty are selected for backgrounds and interests that will best contribute to the achievement of the missions of DOE and other sponsors of ORNL R&D. Faculty appointments also result in improved recruitment of students in science, mathematics, computer science, and engineering through faculty mentoring and ORNL staff contacts and interactions.

Minority Educational Institutions

ORNL interacts extensively with HBCUs and other MEIs, through mechanisms such as the DOE Science and Technology Alliance, the Waste Management Consortium, and the National Consortium for Graduate Degrees for Minorities in Engineering, Inc. (GEM). Program activities and initiatives are under way with a number of institutions, with the overall goal of increasing the number of scientists and engineers available in the future.

The number and dollar value of the Laboratory's program interactions with HBCUs and other MEIs continues to expand. ORNL administers some 26 subcontracts with MEIs, representing commitments of more than $4.5 million. Six of these subcontracts support customized internship programs, through which training assignments in ORNL divisions, primarily in technical support areas, are provided for students.

The main emphasis of these interactions is on generating collaborative opportunities through internal and external interactions. Internally, the program emphasizes communication of Energy Systems' MEI program objectives; externally, MEI participation in research is encouraged through workshops, established contacts, mutual visits, and professional assistance.

The Laboratory is a partner with Los Alamos National Laboratory and Sandia National Laboratories in the DOE Science and Technology Alliance, which links these facilities with the Ana G. Méndez University System in Puerto Rico, New Mexico Highlands University, and North Carolina A&T State University (NCA&TSU). A memorandum of understanding (MOU) with the University of Puerto Rico aims to increase interactions with Hispanic institutions.

ORNL provided support to New Mexico Highlands University in the establishment of a library to support the university's efforts to achieve and maintain Accrediting Board for Engineering Technology accreditation for its School of Engineering Technology. ORNL also supported precollege students and faculty through a special initiative developed last year.

Through the Alliance, ORNL has provided funding to NCA&TSU to support program administration, student and faculty development, curriculum development, and special precollege programs to help encourage science and engineering students. In addition to existing subcontracts in materials science with NCA&TSU, R&D collaborative efforts between ORNL and NCA&TSU continued in mathematical modeling (symbolic modeling of mechanical manipulators).

The Information Services Division (ISD) of the Energy Systems Information Resources and Administration organization also supported a subcontract with the NCA&TSU Mass Communications Department. Through this subcontract, ISD is developing an internship program that will produce a cadre of professional technical information specialists.

ORNL and Energy Systems have MOUs with three other MEIs: Southern University, Clark Atlanta University, and Tuskegee Institute. In addition to faculty and student appointments, subcontracts with these institutions support mission-related research.

The University of Tennessee at Knoxville

Because of their geographic proximity, ORNL and UTK have long enjoyed a close and mutually beneficial relationship. Many UTK faculty members serve as consultants and research participants at ORNL. ORNL staff, in turn, serve as adjunct faculty and on UTK advisory committees. The UTK Resident Graduate Program in Oak Ridge, which offers courses leading to advanced degrees in a variety of scientific and engineering disciplines, is used by many ORNL staff members.

ORNL and UTK copublish a quarterly journal, *Forum for Applied Research and Public Policy*. The journal has recently published its first "Encore Series" reprint containing articles on mathematics and science education that originally appeared in the spring and summer of 1992.

ORNL has a joint project with UTK to create an Academy for Teachers of Science and Mathematics that serves Tennessee and four other southeastern states, as well as an innovative program of alternative preparation and certification for technical professionals who wish to pursue second careers as science and mathematics teachers.

Science Alliance

ORNL and UTK are partners in the Science Alliance, Tennessee's oldest and largest academic Center of Excellence. This activity, funded by the state of Tennessee, ORNL, and DOE under the state's Comprehensive Education Reform Act, is a prime example of university-laboratory collaboration in the planning and conduct of frontier research. The Science Alliance encourages joint projects between ORNL and UTK, thus fostering a unique environment for research.

The most visible activity under this umbrella organization is the Distinguished Scientist Program, which has attracted 11 scientists and engineers of national and international stature to tenured positions as full professors at UTK and to appointments as senior research scientists at the Laboratory. ORNL and UTK share program costs equally. Substantial positive impacts are evident in the number of personnel and contract awards that have accumulated since the start of these appointments. The Collaborating Scientist Agreement, modeled on the Distinguished Scientist Program, is expected to further expand interactions at all levels.

The Science Alliance also sponsors a summer research program at ORNL for undergraduates and the development of a joint graduate program, including a Master of Science program in biotechnology and a graduate program in measurement and control engineering.

UTK Graduate Schools at ORNL

Two UTK graduate schools are located at ORNL. The Oak Ridge Graduate School of Biomedical Sciences (ORGSBS) is more than 20 years old, and the Graduate Program in Ecology is in its second decade. Both programs at ORNL provide a home for several UTK faculty.

Housed in the Biology Division at ORNL, ORGSBS offers full-time graduate study for M.S. and Ph.D. degrees and for postdoctoral training. Student support is provided by UTK through research assistantships and federal grants. Most of the school's teaching and research training is

provided by Biology Division staff. Current enrollment stands at 20 graduate students and postdoctoral appointees.

The Graduate Program in Ecology, located within the Environmental Sciences Division (ESD), offers full-time graduate study for M.S., Ph.D., and postdoctoral students and is largely supported by ESD programmatic funds. About 20% of the research training is provided by ESD staff, who also teach courses under adjunct appointments. Enrollment totals about 15 graduate and postgraduate students.

Summary

The Office of Science Education and External Relations projects strong growth and development over the planning period as ORNL's Science Education Center continues to serve as a model for other national laboratories and corporate entities in efforts to enhance the mathematics and science skills of the nation's youth. ORNL is committed to providing innovative precollege educational activities for both students and teachers and to increasing the involvement of university personnel in its R&D activities. These programs assist DOE in achieving its educational mandate, both by providing opportunities for students of all ages to receive training and perform research and by encouraging students to consider advanced studies in energy-related disciplines. College and university interactions make important contributions to technical work force development and to academic science and technology capabilities through sponsorship of student and faculty research and visits at ORNL and through on-campus visits and lectures by ORNL staff. Collaborative research programs with college and university personnel continue to be a highly cost-effective method of helping to achieve DOE and national education goals while benefiting from the strong contributions that academic participants make to fulfilling the Laboratory's important national R&D missions. Participation in educational programs is summarized in Table 7.9

Table 7.9
Participation in science and math education programs

	FY 1992			FY 1993[a]		
	Total	Minorities	Women	Total	Minorities	Women
Precollege student programs						
Special Honors Study	6	0	1	8	1	1
DOE Honors Workshop	61	4	36	59	12	41
Ecological and Physical Sciences Study Center	24,333	2,876	12,300	20,897	1,960	10,400
Clinch River Environmental Studies Organization	18	1	12	20	1	12
Summer Science Experience	50	3	12	77	7	35
Wesleyan College Spectacles	63	12	62	68	10	68
Project SEED	7	2	5	6	0	4
Hispanic SEED (Science and Technology Alliance)	11	11	5	12	12	9
ARC Science Academy	35	3	15	35	3	17
Saturday Academy of Computing and Mathematics (SACAM)	96	3	43	45	2	21
Summer Science Outreach	—	—	—	191	100	95
Regional Science Bowls	—	—	—	295	35	46
Junior Science/Humanities	—	—	—	135	10	69
Women in Science Conference	—	—	—	110	10	110
Special Programs	—	—	—	425	105	208
Total	24,680	2,915	12,496	22,383	2,268	11,136

Table 7.9
(continued)

	FY 1992			FY 1993		
	Total	Minorities	Women	Total	Minorities	Women
Precollege teacher programs						
NSF Workshop	45	7	42	25	4	22
DOE Honors Workshop	4	0	2	5	1	3
Appalachian Regional Commission	11	1	6	14	0	7
DOE Teacher Research Associates	54	5	26	45	8	17
DOE Lyndhurst Fellows	11	2	8	12	0	8
Project SMART Workshops	102	20	90	75	0	68
Hands-On Science Workshop	56	10	5	45	3	41
Adventures in Supercomputing	19	3	13	25	2	17
Science Enrichment	20	2	15	54	19	44
Saturday Academy of Computing and Mathematics (SACAM)	22	1	15	12	0	6
Science and Technology Alliance	2	2	2	2	2	2
UT Teacher Academy	72	11	46	82	9	55
Puerto Rico Institute	22	22	17	332	332	199
UT Administrators Workshop	—	—	—	47	4	20
Health Occupations	—	—	—	30	2	30
Total	440	86	332	805	387	539
Undergraduate programs						
GLCA/ACM Science Semester	18	0	10	16	0	6
Research Semester (SERS)	69	11	27	72	10	37
Summer Technical Internship (HBCU)	86	10	31	106	32	47
Professional Internship Program	34	3	9	64	5	21
Technology Internship Program	19	0	6	33	3	11
HBCU Nuclear Energy Training	6	6	2	4	4	3
HBCU Health/Environment	-	-	-	10	10	4
Service Academies Research Associates	1	0	0	0	0	0
DOE Practicums	3	0	2	5	2	2
Cooperative Education	104	19	24	61	17	19
Science and Technology Alliance	1	1	0	5	5	0
Student Research Participation	37	5	9	30	3	13
Special Summer Program (SERS)	27	6	13	30	2	17
Customized Internships	7	7	14	2	2	2
University of Puerto Rico	3	3	2	7	7	4
Environmental Management	4	4	1	218	216	11
Women in Science Conference	—	—	—	192	19	187
Total	419	75	150	655	137	384

Table 7.9
(continued)

	FY 1992			FY 1993		
	Total	Minorities	Women	Total	Minorities	Women
	Graduate programs					
Service Academy Research	0	0	0	0	0	0
Professional Internship Program	25	1	5	27	3	13
Laboratory Graduate Participation	11	0	3	6	0	2
Graduate Student Research	31	3	14	25	2	8
Nuclear Engineering Research	3	3	1	1	1	0
Law Internship Program	11	1	5	12	0	6
Graduate Education for Minorities	6	6	0	5	5	1
DOE Fellowship Practicums	4	0	1	4	0	0
Research Travel Visits	18	0	2	13	0	1
Materials Research (AIC)	1	1	0	4	2	2
Total	110	15	31	97	13	33
	Postgraduate programs					
ORNL Postdoctoral Program	42	1	4	136	3	22
Hollaender Postdoctoral Program	5	0	0	7	0	2
Postgraduate Research Training Program (Lab co-op)	48	1	8	35	2	8
Fusion Energy Postdoctoral Fellows	4	0	0	3	0	0
Wigner Postdoctoral Fellows	2	1	1	2	1	2
Human Genome	0	0	0	1	0	0
Global Change	1	0	0	3	0	0
Total	102	3	13	187	6	32
	Faculty programs					
Faculty Research Participation	42	1	4	44	9	2
Minority Institution Travel	7	7	4	10	10	3
Research Travel Visits	80	0	6	75	34	18
HBCU Faculty	13	13	2	7	7	1
University of Puerto Rico	1	1	1	0	0	0
Science and Technology Alliance	1	1	1	6	3	1
Great Lakes Colleges	2	0	0	2	0	1
Environmental Management (EMCOM)	3	3	0	7	6	2
Total	150	26	17	151	69	28

[a]Numbers for FY 1993 are best available estimates.

8 • Human Resources

The diverse nature of the work performed at ORNL requires a high-quality, multidisciplinary technical staff and an equally skilled technical and administrative support staff. ORNL is working to attract and retain staff members with the skills and abilities needed to carry out planned programs. This effort includes encouraging professional growth, recognizing achievement, and providing an environment that affords equal opportunities for all.

The Laboratory's Human Resources Division provides direction, leadership, and support in the functional areas of staffing, compensation, training and development, equal employment opportunity/affirmative action (EEO/AA), benefit plans, complaint resolution programs, and personnel relations to Laboratory managers and employees.

Laboratory Personnel

The Laboratory's professional staff is composed primarily of scientists and engineers, who represent about 67% of the total number of employees (Table 8.1). Of the 850 professional scientists, 507 (60%) hold a Ph.D.; 260 of the 860 engineers on staff (30%) hold a Ph.D. Master's degrees are held by 624 (25%) of the total professional population at ORNL. About 87.4% of the total professional staff hold at least a bachelor's degree.

Chemical, mechanical, and nuclear engineers represent the greatest proportion of the professional engineering staff. There are also 436 other physical scientists, 251 life scientists (biological and environmental), and 28 social scientists. ORNL is supported by Energy Systems central organizations, including Engineering; Computing and Telecommunications Services (C&TS); Information Resources and Administration, which is composed of library, technical publications, graphic arts, and printing support; and Procurement.

The average age of all ORNL employees is 43.6 years; it has remained relatively stable since 1986, when it was 43.2 years. An increasing rate of retirement among the total population has caused the average length of service to decrease from 15.4 years in 1986 to 14.0 years in 1992.

The Laboratory had an 81% acceptance rate for employment offers made to Ph.D. applicants during 1992, an increase from 77% in 1991. While some of this increase can be attributed to a tight job market and an uncertain economic outlook, the global marketplace has intensified competition for outstanding scientists and engineers. As a result, ORNL (and other major laboratories) may not continue to enjoy the same level of success in attracting and retaining top professionals. Further, major initiatives at ORNL, including new environmental and high-performance computing programs, are increasing the demand for highly skilled professionals. To meet the challenge of attracting professionals of the caliber necessary to fulfill the Laboratory's missions, more emphasis is being placed on recruiting at leading colleges and universities, job fairs, and professional meetings. The

Table 8.1
ORNL staff composition (CY 1992)[a]

	Ph.D.	M.S.	B.S./B.A.	A.S.	Non-degreed	Total
		Professional staff				
Scientists	507	176	144	5	18	850
Engineers	260	245	271	11	73	860
Management/administrative	129	110	141	3	54	437
Other	29	93	114	20	136	392
Total professional staff	925	624	670	39	281	2539
		Support staff				
Technicians	0	6	97	119	337	559
Union employees (includes crafts, laborers, etc.)	0	1	8	22	989	1020
Administrative/clerical	0	2	67	75	660	804
Other (i.e., supervisors of union employees)	0	0	7	12	90	109
Total support staff	0	9	179	228	2076	2492
Total Laboratory staff	925	633	849	267	2357	5031

[a]Includes full-time regular employees.

Laboratory is also planning to more effectively use the educational "seed" programs by tracking outstanding students. Targeted print advertising in professional journals and magazines is also planned.

In addition, ORNL is increasing its marketing efforts to attract women and minorities through workshops, seminars, and educational programs, including Women's History Month Seminars and the MMES Cooperative Minority Scholarships, which focus on these groups. New programs such as the ORNL Committee for Women and the American Management Association's first annual conference for working women, with the theme "Leadership for the 90's," are being created to improve training and development opportunities aimed at retaining these employees. The Focus on Corporate Utilization Skills (FOCUS) Program provides minority employees with an opportunity to participate in and influence Energy Systems programs.

Every effort is employed to offer competitive salaries and benefit packages. To ensure the continued high caliber of those being hired, the Laboratory has established hiring guidelines that define the academic and professional characteristics being sought in new hires. An ad hoc review process has been reinstituted for prospective employees with Ph.D. degrees and for experienced B.S. and M.S. technical candidates.

Recognition Programs

To ensure continuity in both staff quality and capability, the Laboratory recognizes that it is necessary to attract, hire, and retain outstanding personnel. ORNL strives to provide a suitable environment for research, to provide opportunities for growth, and to reward excellent performance. Several financial and nonfinancial incentive and recognition programs have been established to reward outstanding contributions and significant achievements. The Special Achievement Awards Program is a financial incentive program that recognizes employee contributions at two levels in the organization.

At the division level, individuals are rewarded for overall quality of sustained performance; at the facility or major organization level, employees are recognized based on the achievement of special goals, milestones, and/or assignments of substantial impact on organizational programs. Another program pays Energy Systems inventors for technology licensed or transferred to private industry (see Sect. 7, "Technology Transfer and Science and Mathematics Education").

ORNL participates in the Energy Systems annual awards night, which recognizes outstanding performance in various categories. These include publications, technical achievement, management support service, inventions, operational performance, and administrative/technical support. Special achievements and accomplishments of ORNL employees are also recognized through announcements in a variety of in-house publications (*Energy Systems News, Lab Notes, Inside Line*). Other incentives include participation in professional organizations and meetings, sabbatical leave, and other work-related travel.

Training and Education

The Laboratory's Educational Assistance Program remains an effective tool for helping employees achieve their academic and career goals. The program helps to ensure the proper availability, optimum utilization, and continuing welfare of Laboratory employees. In 1992, over 515 employees participated in this program.

The Laboratory also provides in-house development programs designed to meet the specific education and training needs of its current population. Further, the Laboratory is responding to a heightened emphasis on ES&H issues as well as other cultural and social issues affecting employees and management by expanding specialized training programs such as sexual harassment awareness training and smoking cessation clinics. Finally, the curriculum of courses offered as a part of ORNL's management training is being expanded to include courses that present strategies for communicating across cultural barriers and for appreciating cultural diversity. This area of management training is crucial in preparing managers for the changing work force of the 1990s.

Affirmative Action and Equal Employment Opportunity

The cultural diversity of the work force, especially in the sciences, is increasing. Projections show that by the year 2000, over one-half of those entering the work force will be women, minorities, and persons with disabilities. The Laboratory and Energy Systems are instituting changes in personnel policies that will be required to meet the different demands of this changing work force.

For example, the company's part-time policy and the concept of employee convenience time allow employees greater flexibility in scheduling work hours. The company is also developing "flextime" and "flexible workplace" policies to provide even more scheduling flexibility to employees. The "flextime" program provides a work scheduling system that gives employees discretion in choosing their specific hours of work each day. The "flexible workplace" program will allow employees with temporary and permanent disabilities to work out of their homes for a specified time and also provide the company with a system to recruit qualified individuals with severe disabilities who may need to work at home.

Expansion of management skills is being addressed through a formal cultural diversity training program, increased accountability for equal employment opportunity (EEO) and affirmative action (AA) program components, and responsibility for employee development plans for women and minorities. ORNL has a management/employee-oriented EEO Strategic Plan Implementation

Committee to develop strategies for ORNL to meet its own and other Energy Systems EEO/AA challenges. Additional work force issues are also being identified and considered by an Energy Systems and Martin Marietta Corporate task force.

As access barriers fall and technology evolves, Americans with disabilities are expected to assume a greater role in the future work force of ORNL. The Laboratory will continue its heightened emphasis on recruiting and hiring qualified disabled candidates. Plans to recruit and hire persons with disabilities and Vietnam-era veterans are developed and implemented annually from the EEO/AA office at ORNL. The ORNL Disability Program Oversight Committee, formed in 1991, implements the requirements of the Americans with Disabilities Act and ensures compliance with policies and procedures that relate to the legislation. The committee has addressed accessibility concerns in common area facilities, and a number of modifications (e.g., curb cuts, elevators, automatic doors) have been and are being made.

EEO/AA Structure and Function

EEO/AA is an integral part of all personnel functions and activities for the Laboratory. The ORNL EEO/AA office is a department within the Human Resources Division, and the EEO/AA program site manager reports directly to the ORNL human resources director. A primary responsibility for the EEO/AA program site manager is to monitor activities and to inform Laboratory management about progress made in hiring, promoting, and developing minorities, women, persons with disabilities, and Vietnam-era and disabled veterans. The site manager also monitors and maintains management awareness of areas of concern relative to the program, such as the inability to meet a hiring goal or to maintain on-staff representation of minorities or women at the calculated availability. Overall, the Laboratory's representation of minorities has remained fairly constant (Tables 8.2 and 8.3). The representation of women on staff has continued to increase with a concomitant increase in upward mobility; the number of women being promoted to higher levels is growing.

As part of the EEO/AA office, ORNL employs a full-time counselor to deal with the concerns of salaried employees. The counselor works with staff and management to resolve a variety of employee issues and complaints, including allegations of discrimination and sexual harassment.

Promoting Cultural Diversity

The EEO/AA site manager is responsible for creating and promoting a variety of programs and events to recognize minority groups and individuals, including Martin Luther King, Jr., birthday observances; Asian Pacific Heritage Week; Black History Month; and Hispanic Heritage Month. The manager is also responsible for promoting the importance, benefits, and economic advantages of having a culturally diverse work force.

Developmental Activities

Upward mobility for members of minority groups is receiving special attention from Laboratory management. The Laboratory has undertaken additional recruiting efforts to increase the size of the pool from which minority candidates for management openings can be drawn. Developmental plans are being prepared for salaried minority and women staff members in an effort to identify areas for growth and development.

The formal mentor program, although it makes no guarantees of promotion, can provide increased visibility for an employee, either within his or her own area of work or outside it, depending on the mentor selected. In 1992, 14 ORNL employees, primarily women and members of minority groups, participated in the program, which provides an opportunity for each participant to become

Table 8.2
Equal employment opportunity statistics for 1987

Occupational code	Total (%)[a]		Minority total (%)		White (%)		Black (%)		Hispanic (%)		Native American (%)		Asian/Pacific Islander (%)	
	M[b]	F[c]	M	F	M	F	M	F	M	F	M	F	M	F
Officials and managers[d]	438 (91.4)	41 (8.6)	17 (3.5)	2 (0.4)	421 (87.9)	39 (8.1)	13 (2.7)	2 (0.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	4 (0.8)	0 (0.0)
Professional staff														
Scientists and engineers	1222 (90.6)	126 (9.4)	99 (7.3)	13 (0.9)	1123 (83.3)	113 (8.4)	21 (1.5)	4 (0.3)	13 (0.9)	1 (<0.1)	1 (<0.1)	1 (<0.1)	64 (4.7)	7 (0.5)
Management and administrative	230 (54.2)	194 (45.8)	25 (5.1)	27 (5.5)	205 (41.5)	167 (33.8)	14 (2.8)	19 (3.8)	1 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	10 (2.0)	8 (1.6)
Technicians	467 (75.6)	151 (24.4)	34 (5.5)	19 (3.1)	433 (70.1)	132 (21.4)	26 (4.2)	16 (2.6)	8 (1.3)	1 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	2 (0.3)
All others	941 (54.9)	773 (45.1)	138 (8.1)	116 (6.8)	803 (46.8)	657 (38.3)	133 (7.8)	108 (6.3)	2 (0.12)	3 (0.17)	2 (0.12)	1 (<0.1)	1 (<0.1)	4 (0.23)
Total	3298 (72.0)	1285 (28.0)	313 (6.8)	177 (3.8)	2985 (65.1)	1108 (24.2)	207 (4.5)	149 (3.3)	24 (0.5)	5 (0.11)	3 (<0.1)	2 (<0.1)	79 (1.7)	21 (0.46)

[a]Percentage of total number of employees in occupational category.
[b]M = male.
[c]F = female.
[d]Includes staff members with managerial responsibilities down to the group leader level.

Table 8.3
Equal employment opportunity statistics for 1992

Occupational code	Total (%)[a]		Minority total (%)		White (%)		Black (%)		Hispanic (%)		Native American (%)		Asian/Pacific Islander (%)	
	M[b]	F[c]	M	F	M	F	M	F	M	F	M	F	M	F
Officials and managers[d]	492 (92.7)	39 (7.3)	29 (5.5)	2 (0.4)	463 (87.2)	37 (7.0)	24 (4.5)	1 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	5 (0.9)	1 (0.2)
Professional staff														
Scientists and engineers	1352 (86.5)	211 (13.5)	106 (6.8)	25 (1.6)	1245 (79.6)	186 (11.9)	26 (1.7)	14 (0.9)	14 (0.9)	2 (0.13)	1 (<0.1)	1 (<0.1)	66 (4.2)	8 (0.5)
Management and administrative	323 (61.4)	203 (38.6)	32 (6.1)	18 (3.4)	292 (55.5)	185 (35.2)	16 (3.0)	11 (2.1)	6 (1.1)	0 (0.0)	0 (0.0)	0 (0.0)	9 (1.7)	7 (1.3)
Technicians	390 (69.5)	171 (30.5)	27 (4.8)	20 (3.6)	363 (64.7)	151 (26.9)	22 (3.9)	14 (2.5)	5 (0.9)	1 (0.2)	0 (0.0)	1 (0.2)	0 (0.0)	4 (0.7)
All others	936 (51.7)	875 (48.3)	123 (6.8)	121 (6.7)	813 (44.9)	754 (41.6)	117 (6.5)	108 (5.6)	2 (0.11)	4 (0.22)	1 (<0.1)	3 (0.16)	3 (0.16)	6 (0.33)
Total	3493 (70.0)	1499 (30.0)	317 (6.4)	186 (3.7)	3176 (63.6)	1313 (26.3)	205 (4.1)	148 (3.0)	27 (0.5)	7 (0.14)	2 (<0.1)	5 (0.1)	83 (1.7)	26 (0.5)

[a]Percentage of total number of employees in occupational category.
[b]M = male.
[c]F = female.
[d]Includes staff members with managerial responsibilities down to the group leader level.

better acquainted with the larger Energy Systems organization. Further, through the interactions necessitated by these mentorships, employees have an opportunity to gain additional insights that will be useful in developing their own career plans.

ORNL also conducts succession planning activities to plan for future staffing of key management positions. The Human Resources Division assists ORNL management with this process to ensure that women and minorities are being considered for these positions.

Goals and Strategies

In 1991, Energy Systems issued its "Strategic Plan for Equal Employment Opportunity and Affirmative Action." The plan's vision states that, by the year 2000, Energy Systems is determined to be a recognized leader in America in EEO/AA, with full participation of minorities, women, veterans, and people with disabilities in all categories of work and at all organizational levels.

At ORNL, the Laboratory director appointed a committee to devise a strategic implementation plan and advise Laboratory management on actions that could be taken to optimize ORNL's success in meeting the EEO/AA goals established by Energy Systems. The ORNL EEO/AA Strategic Plan Implementation Committee is responsible for formulating a long-range strategy for ORNL's use in implementing the Energy Systems Strategic Plan.

To meet these objectives, the committee reviewed ORNL's current strategies relevant to achieving the goals; developed ideas and devised long-range strategies for ORNL to use in meeting the objectives; assessed the potential cost of the recommenced strategies; and determined potential risks and benefits of implementing the strategies. The committee developed recommended strategies for ORNL to achieve the goals identified in the plan. These goals and strategies are as follows.

Goal: Eliminate numerical deficiencies of minorities, women, and people with disabilities in our entry and mid-level jobs.

Recommended Strategies: Establish central responsibility for EEO/AA recruiting and hiring with a position in ORNL Human Resources Division devoted to recruiting of minorities, women, and people with disabilities.

Establish a wider variety of employee opportunities with regional higher educational facilities to enable employees to better qualify for Energy Systems jobs and facilitate upward mobility. Highlight the new program when recruiting new employees.

Restructure EEO job category and recruitment statistics and devise a better tracking system for monitoring.

Goal: Achieve 20% of the upper and senior management and top-level scientist and technical positions with minorities, women, and people with disabilities.

Recommended Strategies: Develop upper and senior manager succession plans for promising EEO/AA employees.

Recruit externally for senior managers and top-level scientist and technical positions when none are identified in house.

Goal: Have accessible work areas for people with disabilities.

Recommended Strategies: Establish a continuing committee, including disabled employees, to address facilities improvements and the 1990 Americans with Disabilities Act.

Goal: Be a corporate leader in supporting excellence in education.

Recommended Strategies: Institute formal personal development and leadership training programs in Energy Systems/ORNL for R&D staff.

Establish an effective link between student education programs and ORNL employment offices. Increase the outreach and awareness activities of the ORNL education program.

Goal: Managers and supervisors will model the principles of cultural diversity and EEO.

Recommended Strategies: Promote and implement cultural diversity exchange to maximize the understanding at all levels of ORNL.

Develop a communications program to assist in promoting the purpose of the EEO/AA Strategic Plan.

Goal: Have a consistent record of good community relations, including exceeding our socioeconomic program goals.

Recommended Strategies: Develop a focused and structured community and business relations program.

9 • Site and Facilities

Laboratory Description

ORNL is a large multiprogram laboratory with projects that cover diverse scientific and engineering disciplines. These programs create demands for a variety of building and equipment needs, including specialized experimental laboratories and a large complement of office space. Major utility and waste disposal facilities are also required. The ever-changing description and set of programs that result from the nature of research and development (R&D) and evolving national energy priorities require a high degree of flexibility in the use of the Laboratory's facilities.

Currently, the Laboratory occupies ~2.6 million ft^2 of building space at the main Bethel Valley site and the Melton Valley site to the south. In addition, over 1 million ft^2 of building space at the Oak Ridge Y-12 Plant are allocated to the Laboratory, and ~200,000 ft^2 of space are occupied by ORNL personnel at the Oak Ridge K-25 Site.

ORNL has full responsibility for facilities at its main site and in the surrounding areas. However, for the facilities at the Y-12 and K-25 sites, ORNL has full responsibility for building maintenance but only limited responsibility for supporting utilities.

In recent years, continued growth in ORNL staff, visiting researchers, and guests, along with the location of a number of DOE personnel at the Laboratory site, has dictated the use of many temporary trailer facilities (~50,000 ft^2) as well as the use of local off-site rental space (~60,000 ft^2).

The Laboratory site and facilities were originally developed as part of the Manhattan Project and have evolved to the present under insufficient facility modernization budgets to permit needed building replacement. As a consequence, the average age of Laboratory buildings has been steadily increasing, and the condition of building space and supporting utilities has been declining. Figures 9.1 through 9.6 illustrate the current distribution, use, age, condition, and size of ORNL buildings. Table 9.1 lists estimated facility replacement values. These estimates are based on active functions and do not include replacement of obsolete facilities or costs associated with decontamination and decommissioning (D&D) of existing facilities.

Although past funding limitations have not permitted major upgrades over large portions of the Laboratory site, some of the least desirable space has been replaced through construction projects supported by general plant project (GPP) funds. Nine new office buildings, scheduled for construction within the next two years, will provide about 60,000 ft^2 of additional office space; however, an additional 200,000 ft^2 is needed to relieve overcrowded conditions.

Past approval of a limited number of major line-item requests has permitted construction of some important new research buildings and significant restoration of utility systems. Ongoing projects to upgrade waste management capabilities and utility systems, along with a DOE-budgeted project for reroofing work to begin in FY 1994, will provide much-needed improvements. However, more must be accomplished to provide the kind of facilities needed to support the highest quality research programs.

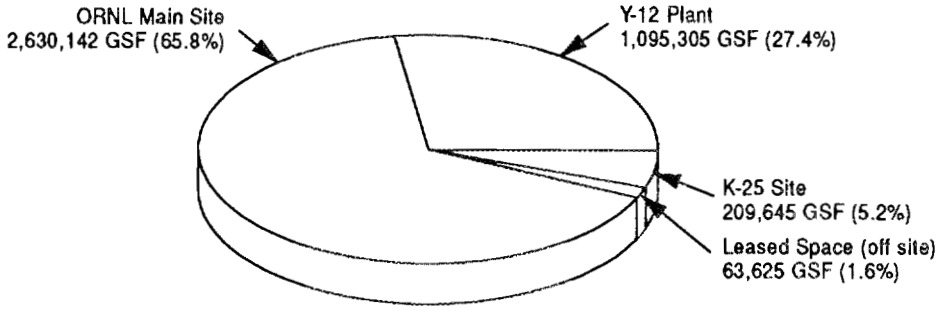

Figure 9.1
Laboratory space distribution—location and building area in gross square feet (GSF).

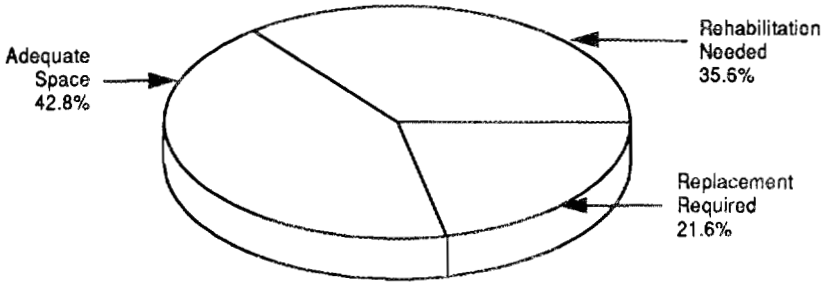

Figure 9.2
Condition of Laboratory space.

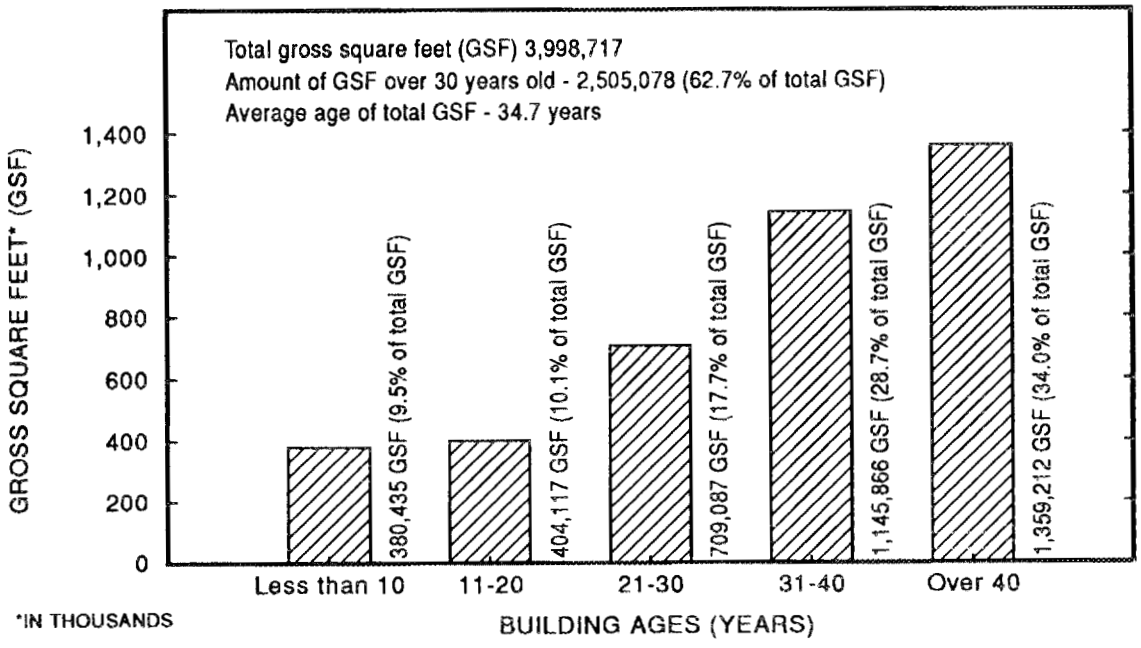

Figure 9.3
Gross square footage of Laboratory buildings, categorized by age.

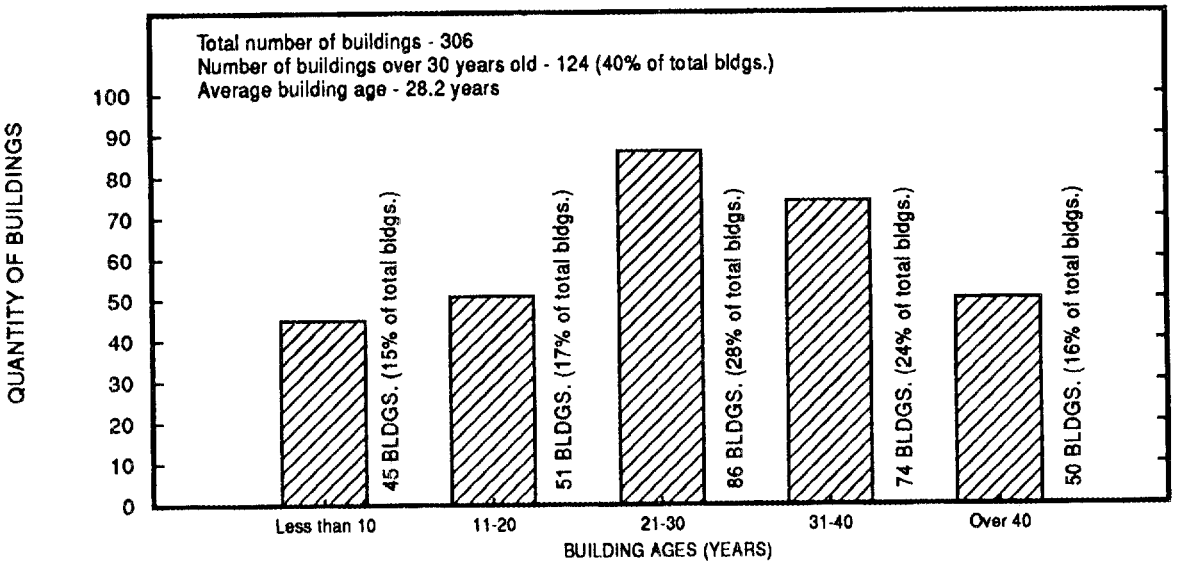

Figure 9.4
Number of Laboratory buildings, categorized by age.

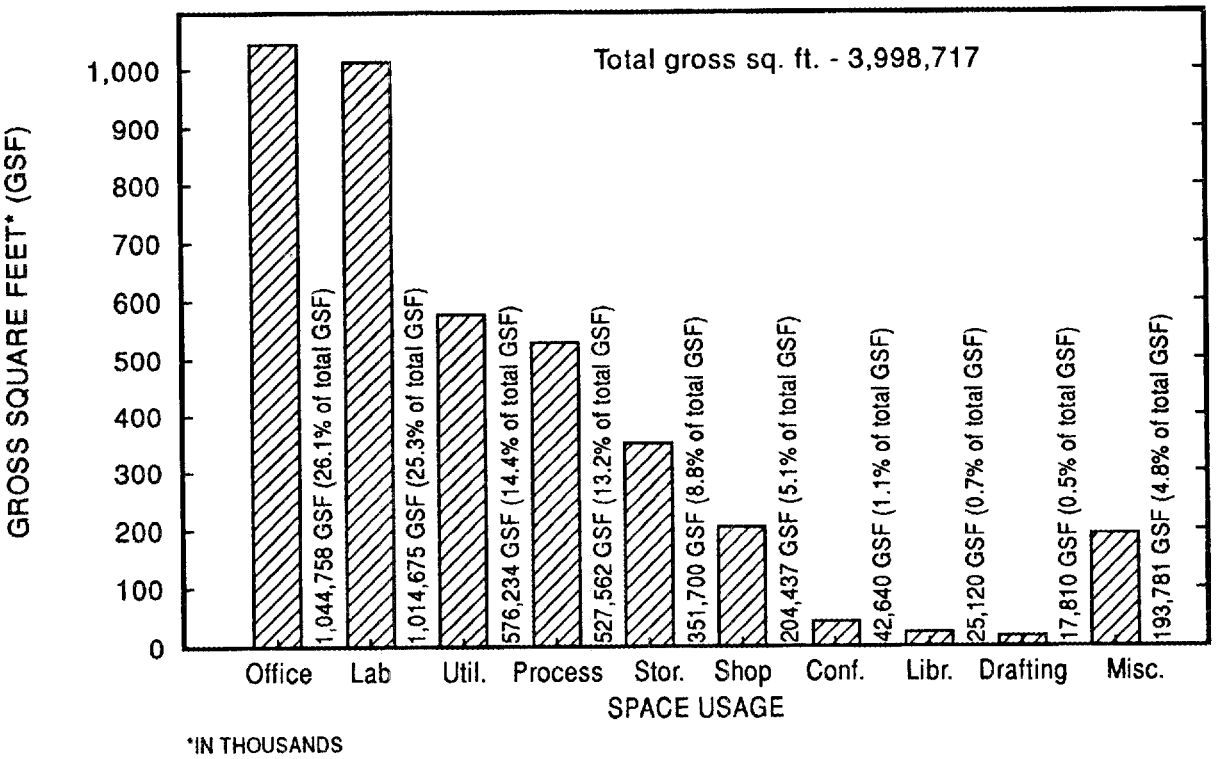

Figure 9.5
Use of Laboratory space.

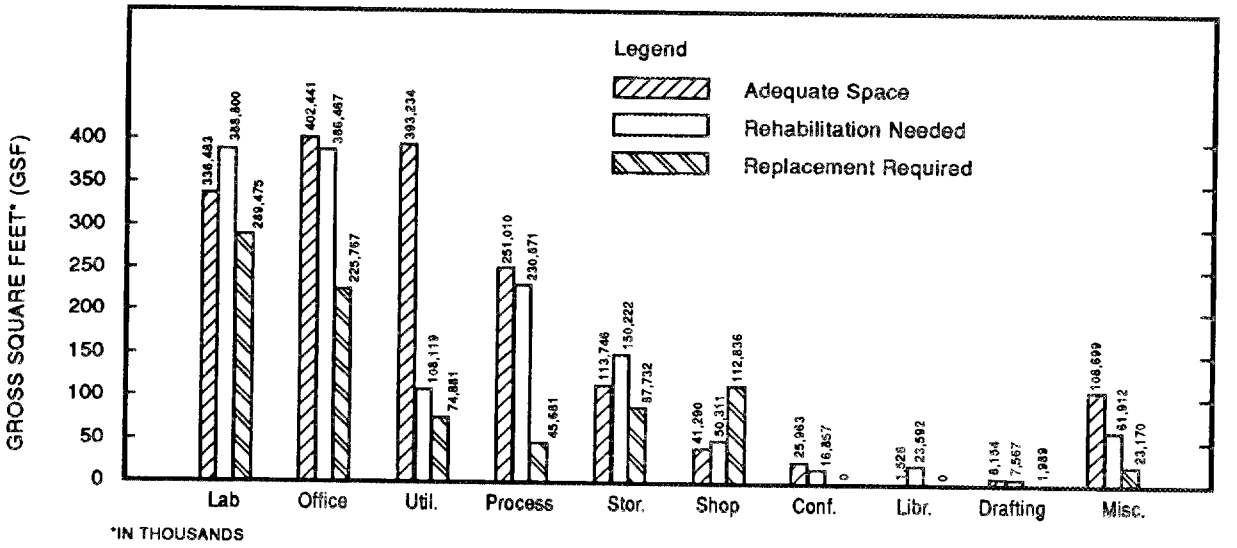

Figure 9.6
Condition of Laboratory space, categorized by use.

Table 9.1
Estimated facilities replacement values

Facilities type	Replacement cost range[a] Lower	Upper
Buildings and structures	730	1,032
Reactors	1,300	1,650
Process facilities	480	725
Accelerators	285	430
Utility systems	240	350
Roads, bridges, and parking	143	176
Security facilities	6	11
Automatic data-processing equipment	66	93
Motor vehicles	11	17
Heavy equipment	6	11
Other equipment and facilities	33	55
Subtotal, fixed price construction	**3,300**	**4,550**
Engineering (35%)	1,163	1,593
Construction support services (20%)	660	910
Operational readiness review (2.5%)	82	114
Construction manager (15%)	495	683
Subtotal	**5,700**	**7,850**
Contingency (40%)	2,300	3,150
Total	**8,000**	**11,000**

[a]In millions of FY 1993 dollars.

Another issue for ORNL is the disposition of facilities that have exceeded their useful life. Over the years ORNL has employed a number of major experimental facilities to conduct its programs. Nuclear reactors, radioisotope production facilities, and centrifuge enrichment facilities have supported many important aspects in the development of the nation's nuclear energy, nuclear medicine, and research capabilities. Some of these facilities now require surveillance and maintenance (S&M) and will eventually require D&D. The Laboratory is faced with significant expenses for these activities. A major funding commitment will be required to properly dispose of these facilities.

A major concern is that DOE funding support for all forms of nonenvironmental capital projects and equipment has declined significantly over the last several years. Figure 9.7 shows that funding for nonenvironmental capital improvements at ORNL has declined by 47% between FY 1984 and FY 1993. Support for specific programs and initiatives must be augmented by support for new equipment and facilities to maintain the Laboratory's capabilities. This issue applies both to R&D sponsored by DOE and increasingly to work for other sponsors as a result of the growing emphasis on partnerships with the public and private sectors.

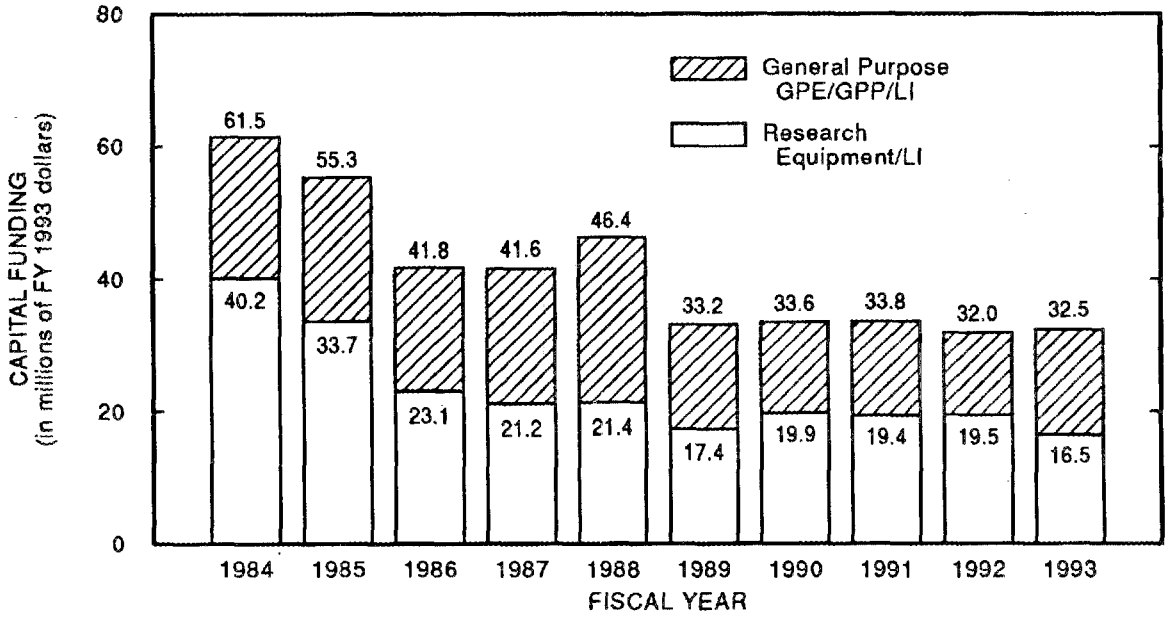

Figure 9.7
Recent funding levels for nonenvironmental capital improvements at ORNL.

Facilities Plans and Options

The objectives of ORNL's site and facilities development plans are to provide high-quality space, reliable utility support, and the additional necessary infrastructure required to produce the appropriate environment for conducting outstanding research on DOE programs. To achieve this goal, it is crucial that capital assets planning be closely coupled to the Laboratory's technical program objectives and plans as described in this document.

In response to recognized national needs, the Laboratory's strategic directions have been set to address four primary themes:

- energy,
- the environment,
- international competitiveness, and
- the fundamental scientific knowledge required to deal with these issues and to keep the United States a world leader in science and technology.

In support of both energy R&D activities and improved U.S. competitiveness, three major programmatic facilities are required:

- the Advanced Neutron Source to serve as the world's most powerful neutron research facility;
- the Center for Biological Sciences to establish an efficient, consolidated research center for biology programs; and
- the Materials Science and Engineering Complex to provide state-of-the-art research facilities for materials programs.

All of these facilities, described in Sect. 4, "Summary of Major Initiatives," include a strong focus on technology transfer through establishment of user facilities and on educational activities through joint programs with universities.

Another major facility required for environmental protection purposes is the Waste Handling and Packaging Plant. This facility will conduct radioactive waste solidification operations and packaging for shipment to the national disposal site.

The Laboratory has placed high priority on two other new building projects: an Advanced Computing Technology Center to provide a first-class computing capability to support research programs and a Center for Education and Technology Transfer to establish improved links with both educational institutions and private industry while simultaneously providing training facilities for ORNL staff.

Finally, a major new project is proposed to allow extensive renovations and rehabilitation of general-purpose buildings and utility systems that have gradually deteriorated for many years, owing to insufficient capital improvement funding for modernization and adaptation to changing program needs. Deterioration is especially evident in buildings that were constructed very quickly for temporary use as part of the Manhattan Project.

The impact of this deterioration is significant. Operational overhead rates have increased from 30% to over 45% during the last several years in order to comply with current environmental, safety, and health (ES&H) regulations governing our facilities and their operations. In addition, some office areas have been vacated because they failed to meet Occupational Safety and Health Administration (OSHA) standards. In combination with limitations on funding for conversion of radiation-contaminated areas to productive office and clean laboratory space, plus a significant increase in the number of on-site guests, this situation has contributed to severe overcrowding.

As illustrated in Fig. 9.2, surveys of building and utility system conditions show that over 45% of the total building space is in need of renovation or replacement, including World War II vintage wood-frame and Quonset-type structures currently used for both office space and laboratories. Many basic systems such as roofs, electrical distribution, piping, and heating and air conditioning have greatly exceeded their designed life expectancy and do not properly meet the needs of current research programs. Another serious problem with building cooling systems is their use of chlorofluorocarbons (CFCs) and the future unavailability of this material.

To meet these facility challenges, ORNL proposes a major facilities restoration project. We view this project as including work that has already begun in a limited way with previously approved line-item upgrade projects in areas such as piping systems, electrical distribution, fire protection, and road safety improvements as funded by DOE's Multiprogram Energy Laboratories Facilities Support (MEL-FS) Program. However, much more needs to be done. Continued renovation and replacement work is required in the following general categories:

- replacement of obsolete buildings,
- building renovations,
- roof replacements,

- heating, ventilation, and air conditioning (HVAC) upgrades,
- central steam plant replacement,
- electrical system upgrades,
- piping upgrades,
- maintenance shops and equipment replacements, and
- parking and grounds improvements.

Funding is also needed for some major general-purpose equipment (GPE) upgrades for health physics instruments and CFC-bearing refrigeration systems.

This facilities restoration project (which does not include environmental restoration and waste management needs) would continue throughout the planning period and into the period ending in 2010. The multiprogram general-purpose facilities section of Table 9.2 shows specific line-item requests supporting this initiative.

This initiative must be supplemented with a vigorous program to manage and ultimately to renovate or dispose of experimental facilities that have exceeded their useful life and that currently require continual S&M to ensure safe shutdown. These inactive facilities include obsolete research reactors, former isotope production facilities, and former biological research facilities. We anticipate eventual elimination of the inactive reactor and isotope facilities as part of DOE's Decontamination and Decommissioning Program. Some S&M funding has been provided by the Decontamination and Decommissioning Program, and DOE is developing a Facility Transition and Management Program. To date, however, funding for ultimate D&D and demolition or renovation for reuse has been unavailable.

Siting of all of ORNL's proposed construction projects is described in the *ORNL Site Development Plan*. In broad terms, this plan adheres to a concept that locates new buildings with existing structures in ways that lead to functional groupings such as the Environmental, Life, and Social Sciences Complex and the Materials Science and Engineering Complex.

General-Purpose Facilities Plans

The Laboratory's general-purpose facilities (GPF) plans are reflected in proposals for (1) multiprogram GPF line items, (2) GPPs, and (3) GPE. As described in the previous section, "Facilities Plans and Options," a major new project is proposed for restoration of general-purpose infrastructure. The proposed line-item construction projects supporting this project are listed in Table 9.2. The associated requirements for GPPs and GPE are given below.

General Plant Projects

Funding for GPPs plays a key role in allowing the Laboratory to implement small construction projects (less than $1.2 million each) required to support Laboratory operations. These projects are of a general-purpose nature and include betterments, renovations, and new construction. They are extremely important to continuing operations where long-term budgeting requirements cannot be foreseen. GPP funding is supporting the construction of nine new office buildings at ORNL during the next two years.

In FY 1992 and FY 1993, ORNL received landlord GPP funding from the Assistant Secretary for Environmental Restoration and Waste Management. In FY 1994, landlord GPP funding responsibility will return to ORNL's designated landlord, the Office of Energy Research. Funding support is requested at the levels shown in Table 9.3.

Table 9.2
Major construction projects[a]
($ in millions)

	Fiscal year								
	Funded construction		Budgeted construction	Proposed construction					Total estimated cost
	1992	1993	1994	1995	1996	1997	1998	1999	
Research program line-item projects[b]									
Solid State Research Facility	3.0								3.0
Upgrade neutron scattering instrumentation				3.8	5.3	4.9			14.0
Advanced Neutron Source (construction)			26.0	88.3	164.6	317.2	471.1	474.8	2748.9
Center for Biological Sciences			0.0	16.0	42.0	40.7			98.7
Upgrade Radiochemical Development Facility ventilation and containment					0.0	8.0	17.0	15.0	40.0
Earth Systems Facility						2.0	10.0	7.6	19.6
Center for Study of Advanced Materials						1.0	8.0	7.5	17.5
Biological Imaging and Photonics Laboratory						1.5	6.5		8.0
Center for Advanced Microstructural Analysis							5.0	14.0	42.2
Composite Materials Laboratory							5.0	15.0	31.0
Solid State Research and Processing Center			2.0	1.0					3.0
Waste management projects									
Bethel Valley LLW-CAT system upgrade (WBS 3.37)	1.0	0.0	6.5	17.0	6.0	0.5			65.0
Upgrade process waste treatment system	4.7	0.0	9.6						14.3
Melton Valley LLW-CAT system upgrade (WBS 3.45)	4.5	15.9	11.5	9.1					41.0
Upgrade sanitary sewer system		2.0	7.0	7.0					16.0
Bethel Valley FFA upgrades			3.6	7.0	8.9	1.0			20.5
Waste Characterization and Certification Facility (WBS 4.48)				2.0	5.5	8.5	2.0		18.0
MVST capacity increase (WBS 3.46)			9.4	22.0	11.0	5.6			48.0
Process Waste Treatment Facility					2.0	13.0	5.0	2.0	22.0
Retrievable Cask Storage Bunker					2.0	2.0	2.0		6.0
SWSA 8						2.0	2.0	2.0	14.0
Interim Waste Management Facility II						1.0	2.0		3.0
Waste Handling and Packaging Plant							43.1	54.5	300.0

Table 9.2 (continued)

	Fiscal year								Total estimated cost
	Funded construction		Budgeted construction	Proposed construction					
	1992	1993	1994	1995	1996	1997	1998	1999	
Multiprogram general-purpose facilities (KG)									
Buildings/facilities revitalization									
A. Replace substandard housing									
Measurement and Controls Support Facility	0.3	0.5							4.73
Central Research and Support Building					5.0	8.0	1.4		14.4
Environmental, Safety, and Health Compliance and Training Facility					5.2	7.4			12.6
Central Maintenance Support and Quality Testing Facility						3.0	9.0	6.0	18.0
Decontamination laundry							2.0	8.0	11.0
Safeguards and Security Building								3.0	16.0
B. Renovate serviceable structures									
Replace deteriorated roofing, priority 1			3.3	3.7	5.0	4.0			16.0
Replace deteriorated roofing, priority 2					4.0	8.0	7.0		19.0
Replace deteriorated roofing, priority 3							4.0	7.0	17.0
Upgrade building HVAC systems, ORNL at the Y-12 Plant							4.0	2.0	6.0
Upgrade building HVAC systems, east end							6.0	8.0	20.0
Upgrade building HVAC systems, west end								5.0	15.0
Restore Central Research Complex									100.0
C. New capabilities									
Advanced Computing Technology Center							3.0	8.0	17.5
Center for Education and Technology Transfer								4.0	13.6
Environmental, safety, and health protection									
A. Environmental protection									
Steam plant environmental improvements							4.0	10.0	20.0

Table 9.2 (continued)

	Fiscal year								Total estimated cost
	Funded construction		Budgeted construction	Proposed construction					
	1992	1993	1994	1995	1996	1997	1998	1999	
B. Safety									
Fire protection upgrade	1.4								4.7
OSHA compliance facility upgrades				2.2	4.3	4.0			10.5
C. Utility restorations									
Upgrade steam distribution system, west end	1.1	5.2	2.7						9.0
Upgrade water system						4.0	12.0	12.0	35.0
Upgrade primary electrical distribution system							3.0	8.0	18.5

[a]Construction data as of August 1993.
[b]Does not include accelerator and reactor improvements and modifications projects.
[c]To be determined.

Table 9.3
General plant project funding from landlord programs by fiscal year
($ in millions—BA)

	1992	1993	1994	1995	1996	1997	1998	1999
Funding	6.0	6.0	9.6	11.0	20.0	20.0	20.0	20.0

General-Purpose Equipment

GPE support is the only source of funds for supplying the Laboratory's support and service divisions with badly needed capital resources (Table 9.4). For many years, the GPE funding level has been insufficient to maintain a modern research facility. ORNL has relied heavily on receipt of these funds to provide critical replacements. ORNL is experiencing an equipment request backlog exceeding $14 million for FY 1993. Items not funded in FY 1993 will still be required and thus added to FY 1994 funding requirements. ORNL receives about $3 million annually for GPE requirements of about $8 million to $9 million for maintenance and continuing needs. Typical types of capital equipment procured with GPE funds include the replacement of underground storage tanks, vehicles, shop and maintenance equipment, personnel and environmental monitoring equipment, computers, test equipment, security and fire protection needs, and other items related to the general operation and upkeep of ORNL.

In addition to the continuing need for multiple-use GPE funding, there are two special areas of critical equipment needs: (1) upgrade of health physics instruments as a required Tiger Team corrective action and (2) replacement of CFC-bearing compressor equipment used in cooling systems. These are itemized separately in Table 9.4. The compressor replacements are needed to comply with the requirements of the Clean Air Act. Table 9.5 provides a description of ORNL's capital equipment investment and its associated annual replacement requirements.

Table 9.4
General-purpose equipment funding from landlord programs by fiscal year
($ in millions—BA)

	1992	1993	1994	1995	1996	1997	1998	1999
Multiple-use	3.0	3.0	9.6	10.0	10.0	7.5	7.5	7.5
Health physics instruments	—	0.2	1.5[a]	2.5[a]	0.2	0.2	0.2	0.2
CFC compressor replacement	—	—	5.0	5.0	5.0	5.0	5.0	5.0

[a]An additional $0.5 million of operating funds is requested in FY 1994 and FY 1995 to support the replacement of health physics instruments.

Table 9.5
Capital equipment investment and age

FIS asset code	Asset code description	Current asset value[a] ($ in thousands)	% Depreciated	Average useful life (years)	Estimated annual replacement expense[b] ($ in thousands)
610	Communication System	3,683	27	12	404
620	Fire Alarm System	631	100	25	25
710	Heavy Mobile Equipment	3,681	73	10	368
715	Hospital & Medical	422	41	10	42
720	Lab Equipment	122,384	49	20	6,119
725	Motor Vehicles & Aircraft	8,434	63	10	843
730	Office Furniture	3,174	57	10	317
735	Process Equipment	22,694	49	25	907
740	Railroad Rolling Stock	0	0	0	0
750	Security & Protective Equipment	301	35	15	20
755	Shop Equipment	18,733	52	20	936
760	Reserve Construction Equipment	0	0	0	0
770	Automated Data Processing	45,349	64	7	6,478
799	Miscellaneous Equipment	3,604	48	10	369
	Total	233,090			16,819

Current Multi-Use GPE funding (FY 1993) 3,000
Proposed Multi-Use GPE Funding (FY 1994): 9,552

[a]Total, uninflated original cost.
[b]Total inflated original cost divided by average useful life.

Inactive/Surplus Facilities Plan

A large number of facilities at ORNL are currently inactive or surplus, or are expected to become so in the next several years. These facilities are either no longer needed for their original purpose or are old and deteriorating to the point that continued upkeep as operational facilities is not cost-effective. A large portion of these facilities are also contaminated with radioactive or hazardous materials and have no programmatic support from DOE. At present, the expense of S&M for these facilities is borne primarily by division or Laboratory overhead. As a result, research programs are indirectly financing the cost of ensuring adequate containment, and mission-oriented R&D activities are cut back proportionately to provide the necessary funding. A new DOE program may provide minimal funding support for transition of inactive/surplus facilities into the DOE D&D program.

Laboratory-wide surveys have been conducted to scope the number of inactive/surplus facilities and to determine the estimated annual cost for S&M. The approximate number of facilities in this category and the estimated annual expense are shown in Tables 9.6 and 9.7, respectively. These results indicate that at least 80 individual facilities are expected to be inactive or surplus by FY 1996, with a conservative estimate of annual expenditure for S&M of $6.5 million in that year. These costs do not include the cost of eventual D&D, which is expected to be orders of magnitude higher.

Many of the facilities identified in the survey can be prepared for and submitted to the new DOE Environmental Restoration Facility Transition and Management Program. Once these facilities are accepted and transferred, that program then assumes the cost of continued S&M and the responsibility for transfer to the Decontamination and Decommissioning Program, which guides the ultimate disposition of the facility.

Facilities Resource Requirements

Table 9.2 lists ORNL's currently proposed major construction projects along with the estimated funding requirements to implement these plans.

Table 9.6
Schedule of ORNL facilities that are currently inactive/surplus and projected to become inactive/surplus[a]

	Number of facilities					
		Fiscal year				
	Current	1993	1994	1995	1996	Total
Research reactor and related facilities	10	5			9	24
Hot-cell facilities	1	11			2	14
R&D laboratories	16	3	3			22
Support facilities	6	1	1		3	11
Miscellaneous facilities	7	2				9
Total	40	22	4	0	14	80
Cumulative total	40	62	66	66	80	

[a]Facilities not part of the DOE Environmental Restoration Decontamination and Decommissioning Program.

Table 9.7
Projected resource requirements for annual surveillance and maintenance (S&M) of ORNL inactive/surplus facilities[a]

	S&M cost ($ in thousands)				
		Fiscal year			
	Current	1993	1994	1995	1996
Research reactor and related facilities	753	1222	1369	1369	2116
Hot-cell facilities	100	1275	1275	1275	2605
R&D laboratories	1268	1688	1763	1763	1763
Support facilities	40	45	61	61	71
Miscellaneous facilities	9	9	9	9	9
Total annual S&M cost	2170	4239	4477	4477	6564

[a]Facilities not part of the DOE Environmental Restoration Facility Transition and Management Program or Decontamination and Decommissioning Program.

10 • Information Resource Management

The value of information in all of ORNL's activities is widely recognized, and management of information resources is addressed through a program that includes talented staff, a variety of equipment, and increasing levels of automation and connectivity. Additional detail on computing and networking issues summarized here is provided in the *Strategic Plan for Computing at Oak Ridge National Laboratory* (ORNL/PPA/INT-91/2). Martin Marietta Energy Systems, Inc., publishes annual long- and short-range plans that provide additional detail, particularly on efforts that include other Energy Systems operating units. An Energy Systems information resource management (IRM) strategic plan has been drafted and is undergoing review.

Goals and Objectives

The Laboratory's goals for IRM are to maintain, acquire, and develop tools, techniques, and applications that support the information needs of ORNL programs and to ensure the accessibility, integrity, and security of the information generated or required in Laboratory operations. These goals support the Laboratory's primary missions.

Energy Systems central organizations, notably Computing and Telecommunications Services (C&TS), Information Resources and Administration (IRA), and Procurement, will provide assistance in achieving these goals. ORNL will pursue cooperative research and development agreements (CRADAs) and other industrial partnerships that support these goals.

Specific goals with implications for IRM include ORNL's intention to become a leader in the development and application of advanced computational techniques and high-performance computing resources to problems in science and engineering. The principal focus for achieving this goal is the Center for Computational Sciences (CCS), described in detail in Sect. 4, "Summary of Major Initiatives." Additional scientific computing activities within ORNL programs are described in Sect. 5, "Scientific and Technical Programs."

ORNL is committed to providing managers with the best administrative tools and the most accurate and timely information possible within a framework of efficient and cost-effective delivery. The objective is to enable the best and most efficient management of the research programs being carried out at ORNL.

High-speed, seamless networking is the key to efficient use of information and computational resources; thus, network improvement is a high-priority goal. Objectives include expanding ORNL's growing fiber-distributed data interface (FDDI) and Ethernet services and remaining a major backbone node on the Energy Sciences network (ESnet). Improvement of the existing telecommunications system is an Energy Systems objective.

ORNL is an internationally recognized leader in the management of scientific and technical information. The Laboratory intends to maintain this leadership by continuing to apply technical

proficiency, computer programming and processing capability, and information management expertise to provide users with access to information.

Records will be managed effectively to meet all applicable corporate, contractual, sponsor, statutory, and regulatory record-keeping requirements. Centralization and automation of records management functions will increase. Assistance in this area will be provided by the Information Services Division (ISD) of the IRA organization.

Current Situation

The IRM environment at ORNL includes a broad range of scientific and administrative computing resources with growing connectivity provided by networking.

Traditional scientific computing and most administrative computing resources are provided to ORNL through the Energy Systems C&TS organization. The ORNL Office of Laboratory Computing (OLC) reports to the ORNL director and provides the management contact for C&TS. The CCS is administratively part of the Physical Sciences and Advanced Materials Directorate. Also located within this directorate is the Computing Applications Division, which provides scientific programming support to other ORNL divisions. The ORNL Instrumentation and Controls Division provides maintenance services for personal computers (PCs) and workstations. The Energy Systems IRA organization provides library and information services. Records management is the responsibility of line organizations.

A number of ORNL divisions have significant computing interests, ranging from heavy use of traditional computing platforms to research in the effective use of massively parallel processing architectures. These efforts are described in Sect. 5, "Scientific and Technical Programs."

Through the efforts of C&TS and Procurement, ORNL divisions are provided with a number of services that strengthen the overall institutional computing effort, including a just-in-time system for purchase of PC hardware and software; price agreements for scientific workstations; and workstation and PC support. A PC Plan provides management control and tracking of PC and workstation acquisitions. ORNL participates in the Energy Systems computer security efforts, including a software license compliance program.

Telecommunications activities, systems, and services (except for network/computer research and development) for all Energy Systems organizations are overseen by a Computing and Telecommunications Standards Board (CTSB). The CTSB is composed of senior-level managers representing the major Energy Systems computer users (including ORNL), the Computing and Telecommunications Security Organization, a spokesperson for the corporate Computer-Aided Productivity effort, and an independent chairperson.

Scientific Computing

In 1992, ORNL was chosen as one of two DOE High Performance Computing Research Centers. The CCS was created to manage this effort, which supports the national High Performance Computing and Communications (HPCC) initiative (see Sect. 4, "Summary of Major Initiatives").

With the advent of high-performance computers in the CCS and scientific workstations in many ORNL divisions, the pool of remaining central scientific computing systems has been shrinking. At the end of FY 1992, a Cray X-MP was shut down. An IBM 3090-150e running MVS continues to support a number of projects that require this environment; it is scheduled to be shut down at the end of FY 1993. A VAX 6000-420 running VMS and a DECsystem 5810 running ULTRIX provide shared interactive environments. These machines primarily serve divisions or projects that do not have sufficient capacity or functionality in their own systems. They also provide

electronic mail (e-mail) service to many users. C&TS operates these systems and provides a variety of user support services.

Many ORNL divisions provide shared systems for their scientists. Historically, these have been VAX-class systems. Scientific workstations are beginning to replace these systems for division-wide use, and they are being acquired for use by individuals or small groups. ORNL acquired approximately 1400 PCs and 115 workstations during FY 1992.

Central scientific computing is funded primarily through cost recovery from the programmatic funds of users. Distributed scientific computing resources are provided from programmatic funds or divisional overhead.

Administrative Computing

As is true in many other areas of computing, the paradigm for administrative computing is undergoing a profound change. Utilities ranging from electronic mail (e-mail) to the central cost accounting system have until now been based on large central mainframes. Efforts are under way to move away from this model and toward a distributed computing environment based on desktop workstations and a client-server model for applications. C&TS has impaneled a committee to define an Administrative Computing Environment Strategy that will govern the development of computing at Oak Ridge for the next five years. This committee, which includes representation from ORNL, is defining the infrastructure standards necessary to support the client-server applications that will deliver administrative computing.

Networking

ORNL is a major ESnet hub, connected directly to four other sites. It is scheduled to be in the first round of sites to be upgraded from T1 to T3 service. ORNL is also served by SURAnet, the regional NSFnet, at T1 speeds.

FDDI fiber-optic lines (100 megabits per second) now reach 17 ORNL buildings at the ORNL and Y-12 sites. This network has been designed to connect high-performance systems, traditional host systems, and the Internet access point and to reach to within 300 m (1000 ft) of most scientific staff.

A large logical Ethernet (10 megabits per second) has been expanding rapidly and now connects over 1500 nodes. A system of 9.6-kilobit/s asynchronous lines, called the System Select Network (SSN), reaches the vast majority of ORNL offices.

Scientific and Technical Information

ORNL is home to one of the most extensive and authoritative complexes of scientific data and information analysis centers in the United States. A complex of about two dozen information analysis centers is managed by ORNL's Environmental Sciences and Health Sciences Research divisions. More than 200 textual and/or numeric databases cover various technical disciplines, in support of DOE and other customers. Other comprehensive sources of information include a network of libraries managed by ISD, which offer access to over 400 databases.

The management of scientific and technical information activities, from creation through capture and organization, publication, storage, and finally destruction of obsolete information, is supported through ISD and the Publications and Graphics divisions of IRA. Most of these activities are carried out electronically. ISD also provides other tools for managing, organizing, accessing, and storing internal and external information resources through records and document centers and customized databases. The IRA Laboratory Records Department ensures that scientific and technical

information generated at ORNL is transmitted to DOE's Office of Scientific and Technical Information.

Compilation of the research products of the Laboratory as internal publications, journal articles, presentations, etc., is supported by the Publications and Graphics divisions of IRA. IRA also offers electronic publishing support.

ORNL's information management capabilities are widely recognized; two recent examples of this recognition are the selection of the Laboratory as the archival repository for data from the Atmospheric Radiation Measurement (ARM) program and the designation of ORNL as a component of the World Data Center System by the U.S. National Academy of Sciences.

The ARM archive will be the primary point of contact for the general scientific community seeking data from the ARM Project. A computerized system is required to store and manage the tens to hundreds of terabytes of data that will be produced by ARM over the project's 10-year life. The ARM archive staff are developing the data management software and acquiring the first increment of a mass storage system that will be able to store approximately 5 terabytes of data. This activity is described in more detail in Sect. 5, "Scientific and Technical Programs."

The World Data Center System was created in response to the need of the international scientific community for a system to manage critical data related to trace gas cycling. The system, established in 1960 by the International Council of Scientific Unions, supports the data needs of the geophysical community. It is a prime method of research data exchange and archiving for the international research community, with a total of 44 data centers worldwide. The ORNL center, designated the World Data Center-A for Atmospheric Trace Gases (WDC-A), is a component of the Carbon Dioxide Information Analysis Center (CDIAC) in ORNL's Environmental Sciences Division. The center will acquire, assure the quality of, document, archive, and distribute data and information focused on the study of atmospheric trace gases, particularly those important to the analysis of global change issues.

Brief descriptions of some selected ORNL information centers and databases follow.

Center for Environmental Engineering • The process of understanding and resolving many environmental problems and achieving the opportunities to do so requires coordinated multidisciplinary efforts among research divisions within ORNL and interactions with other national laboratories, universities, and industry. The Center for Environmental Engineering is being developed to enhance multidivisional cooperation in R&D and in development and testing in areas of environmental restoration and waste management.

Carbon Dioxide Information Analysis Center • The CDIAC is a data management and distribution center that develops, collates, and provides extensive quality assurance audits on databases that are critical to understanding global change. As an issue-oriented center, it supports the needs of CO_2 research and potentially related environmental consequences such as the "greenhouse effect." Its holdings include such diverse information as tree-ring chronologies, surface air temperature anomalies, atmospheric concentrations of CO_2 and other greenhouse gases, and CO_2 emissions estimates from fossil-fuel burning. Its user constituency comprises basic researchers generating and using raw data; those doing integrated assessments needing multidisciplinary, often derived data; and decision makers needing concise summaries of complex information.

As an example, CDIAC produces the Carbon Dioxide Emissions Data Base, which provides annual global and national CO_2 emissions and per capita emission rates from fossil-fuel burning and cement production. This well-documented data set is the basis for projecting future atmospheric CO_2 concentrations and is used as input for global climate modeling. The newsletter *CDIAC Communications* reaches more than 7500 researchers and decision makers in 150 countries. CDIAC's *Trends* series provides concise presentations of data and descriptive material on emissions and atmospheric concentrations of greenhouse gases as well as long-term global and U.S. temperature data. CDIAC also houses the WDC-A. Future initiatives include developing interactive data analysis systems using networked computers throughout the world. CDIAC is sponsored by DOE's Global Change Research Program.

Toxicology Information Response Center • The Toxicology Information Response Center (TIRC) provides information on individual chemicals, chemical classes, and a wide variety of toxicology-related topics for scientists, administrators, and the public. TIRC synthesizes comprehensive literature packages to meet specific requests. Formats include custom searches of computerized databases, manual literature searches, annotated and/or keyworded bibliographies, or written summaries of the literature. TIRC is sponsored by the National Library of Medicine.

ORNL Environmental Restoration Data Management System • The ORNL Environmental Restoration Data Management System supports compliance with state and federal regulations mandating corrective actions at sites contaminated with radioactive and/or hazardous wastes. The Numeric Data Base serves as a central repository for technical data generated by the program and other applicable studies. These data are used to evaluate the condition of the environment as it relates to ORNL's past waste management practices and to justify decisions on corrective action. The categories of technical data include well construction parameters, groundwater hydrology and quality, geology, soils/sediments, surface water hydrology and quality, meteorology, biological monitoring, and waste inventory. Based on the data management experience gained through this effort, ORNL has assumed a key role in developing a consolidated database for environmental data associated with environmental restoration activities at all Energy Systems facilities.

Oak Ridge Environmental Information System • The Oak Ridge Environmental Information System (OREIS) is being developed to meet the data management/access requirements for environmental data as specified in the Federal Facilities Agreement (FFA) and the Tennessee Oversight Agreement. The FFA, a tripartite agreement between DOE, the Environmental Protection Agency (EPA), and the state of Tennessee, requires DOE to maintain one consolidated database for environmental data generated by environmental programs (restoration, compliance, and surveillance) at DOE facilities on the Oak Ridge reservation. The major goals of OREIS are to consolidate data of known quality, to maintain the integrity of the database, and to give a wide variety of users access to the data. The types of data to be incorporated into OREIS include measurement data on groundwater, surface water, sediment, soils, air, and biota. OREIS will also contain extensive descriptive and qualifier metadata to help define data quality and to enable end users to analyze the appropriateness of using the data for other purposes. Another important aspect of the measurements is their spatial context; OREIS will provide a comprehensive library of map data and geographic information system tools to analyze and display spatial relationships of the data.

Remedial Action Program Information Center • The Remedial Action Program Information Center (RAPIC) serves the technical information needs of DOE's remedial action projects; these include the Surplus Facilities Management Program, the Formerly Utilized Sites Remedial Action Project, and the Uranium Mill Tailings Remedial Action Project. RAPIC maintains the Nuclear Facility Decommissioning and Site Remedial Actions Data Base, a comprehensive, centralized source of information on the scientific, technological, regulatory, and socioeconomic aspects of decommissioning radioactively contaminated facilities and associated site remedial actions. The database contains 7000 records. Ten volumes of a bibliography have been published.* RAPIC also maintains the Remedial Action Contacts Data Base, which contains the names, addresses, telephone numbers, technical areas of interest, and program involvement of 1100 individuals involved in contaminated site remediation, and publishes an annual directory from this database. RAPIC staff members provide technical assistance to DOE Remedial Action Program staff and contractors on request.

Environmental Mutagen Information Center • The Environmental Mutagen Information Center (EMIC) collects and analyzes experimental data from papers reporting on the

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**Nuclear Facility Decommissioning and Site Remedial Actions,* ORNL/EIS-154, Vols. 1–10, Martin Marietta Energy Systems, Oak Ridge National Laboratory, 1980–1989.

evaluation of chemical agents for genotoxicity. EMIC has indexed more than 78,000 papers reporting on more than 22,000 chemicals.

The EPA Genetic Toxicology Program was started using EMIC's collected data file as the basis for its continuing review of short-term tests for genetic toxicology. These data were subjected to strict guidelines for data acceptability, and all evaluations were subjected to review by appropriate panels of experts. The resulting Gene-Tox Data Base contains peer-reviewed evaluations on more than 4600 chemicals evaluated in one or more of 73 short-term bioassays for genotoxicity. This database provides information allowing correlation between chemical structure and genetic activity.

Information from the EMIC file and the Gene-Tox Data Base is incorporated into considerations for regulatory action and is included in the publications of the International Agency for Research on Cancer. EMIC is sponsored by the EPA and the National Institute of Environmental Health Sciences through the National Library of Medicine; Gene-Tox is sponsored by the EPA.

Chemical Unit Record Estimates Data Base • To develop guidelines and limits for controlling chemical substances by a valid scientific approach, various offices within the EPA gather and evaluate information and prepare assessment reports. The Chemical Unit Record Estimates (CURE) Data Base, a comprehensive database designed and implemented by EPA's Office of Health and Environmental Assessment (OHEA) and ORNL, communicates this information within the agency and facilitates the chemical regulatory process.

CURE currently comprises five subfiles: a chemical dictionary, a bibliography file, an experimental data file, a central summary file, and a comment file. The chemical file lists 1900 chemicals, classified according to the structural categories developed in the EPA Gene-Tox Program. This unique database provides a basis for structural activity to span genetic toxicology, low-dose toxicology, and carcinogenicity. To provide technically sound and user-friendly services to a large range of EPA personnel, three disseminating vehicles are being tested at ORNL:

- CURE-PC, a stand-alone, read-only desktop version of the database. CURE-PC excludes information from the Health Effects Assessment Summary Tables (HEAST) and the OHEA ADI documentation tables. It searches by chemical name, synonym, or name fragment; Chemical Abstracts Service (CAS) registry number; or document identifiers. CURE-PC includes CURESYN, a desktop resource for document preparation and other applications, and can also be used to find CAS numbers, synonyms, or EPA document information. A specialized version, HEAST-PC, contains information from HEAST and CURESYN for the HEAST compounds.
- CURE-Friendly, an interactive system that allows searches of the complete CURE database on the IBM mainframe computer in the EPA's Environmental Criteria and Assessment Office in Cincinnati (ECAO-CIN). It searches by target organ, cancer type, and other parameters, in addition to the search terms for CURE-PC. Several output formats are available. Document preparation and other applications are supported.
- CURE Central INQUIRE, the complete CURE database on the ECAO-CIN computer. This interactive system can search for more than 250 data elements, such as chemical and document identifiers, risk estimates, and experimental data parameters. It requires no individual software and uses INQUIRE user language. Output formats are determined by the user. This is an excellent resource for modeling, data associations, or the generation of specialized formats. It was also used to generate the new HEAST.

Human Genome Management Information System • The Human Genome Management Information System (HGMIS) serves as a primary information resource for DOE's Human Genome Program, in support of the DOE Office of Health and Environmental Research (DOE-OHER) role in the national effort to map and sequence the human genome. As a result of its successful work with DOE, the National Center for Human Genome Research (NCHGR) at the National Institutes for Health has joined DOE in support of HGMIS to produce a joint DOE/NCHGR bimonthly newsletter, *The Human Genome News*. Another communication resource, *Radon Research Notes*, in support of the DOE-OHER Radon Research Program, began in 1990.

Information Management Activities • Desktop publishing techniques have been developed for several outreach applications. A PC-based expert system, called NERC (for "NEPA Environmental Review and Compliance"), is under development for the ORNL Office of Environmental Compliance and Documentation. NERC is used in preparing documentation of compliance with NEPA requirements and other applicable federal, state, DOE, and ORNL standards for environment, safety, and health. Additional expert systems include Air Permit Regulations and Determination of RCRA/CERCLA Compliance.

Business Information

As a business unit of Energy Systems, ORNL follows a policy of treating records in an integrated fashion as a corporate resource. The records management program is designed to minimize the paperwork and record-keeping burden, minimize the cost of records management activities, and maximize the usefulness of records. Techniques for automation, centralization, and more effective management of business information are being addressed as part of administrative computing.

Technology Transfer

Technology transfer related to computing is coordinated by OLC. OLC provides ORNL representation on the Defense Programs Technology Area Coordinating Team (TACT) for Computing Architecture and Applications. This TACT has identified several priority areas:

- gigabit network technology,
- materials by computer design,
- automotive design and manufacturing,
- software tools, and
- banking.

Work is under way on the following computing-related CRADAs: Evaluation of Advanced Architectures, with Intel and with IBM; Atomistic Simulation of Materials, with Hoechst Celanese; Development of a Comprehensive Model, with Concurrent Technologies and Weldment Corporation; and High-Performance Thermoelectric Materials, with Marlow Industries.

Agreements are being finalized on the following: Parallel Distribution of Access to Large Data Archives, with Kendall Square Research; Testing of High-Speed Network Components, with IBM; Testing of High-Speed Networks, with IBM and BellSouth; and Automotive Computing, with GM, Ford, and Chrysler.

Other potential partnerships are in various phases of discussion.

Strategies

Scientific Computing

ORNL will support distributed scientific computing as this resource increasingly takes the place of central computing. The decline in the need for and use of central computing systems will be addressed through increasing support for distributed scientific computing (at divisional and desktop levels) by facilitating the acquisition, maintenance, and use of systems for this purpose. This includes the provision of servers for sharing of information and services. Through the services of the C&TS organization, ORNL will provide UNIX systems to supply the functions and capacity not available through the CCS or distributed resources.

ORNL will continue to monitor the use and functionality provided by existing central scientific computing systems. Depending on capacity requirements, existing systems may be shut down or new systems may be added. Any expansion of central systems will be accomplished by the addition of open systems, rather than proprietary environments. In FY 1994, the workload of the IBM 3090-150e will be moved to an IBM system with available capacity at the Oak Ridge Y-12 Plant. This should reduce overall costs for software and for hardware maintenance.

ORNL encourages the acquisition of scientific workstations and of PCs to facilitate the growth of computational science and the use of computers as an office tool. A new high-performance workstation price agreement is in negotiation. This will include agreements for two families of workstations: those optimized for computation and those optimized for graphics. A pricing agreement is also being established for workstations optimized for database management system (DBMS) operations. The contract for just-in-time delivery of PCs is being re-bid to accommodate changes in technology.

Administrative Computing

C&TS is progressing toward an open-system architecture and a client-server-based environment for administrative computing. The Administrative Computing Environment Strategy and the Open System Implementation and Migration initiative being developed by Energy Systems will facilitate the removal and replacement of obsolete, proprietary technologies.

A central Energy Systems committee, the Information Management Task Team (IMTT), is charged with studying ways of improving the efficiency and efficacy of all aspects of Energy Systems administration and management, but with particular emphasis on information management. An IRM strategy for Energy Systems has been drafted by an IMTT committee, with input from the Administrative Computing Environment Strategy team. This strategy is based on three foundation concepts:

- Quality. The correct information—that which is of value to the company and can be shared across multiple business units—will be managed correctly.
- Consistency. Corporate information resources will be adequately protected from unauthorized use or change.
- Availability. Those who need information will have access to it.

A program for implementing the strategy has been outlined. The Energy Systems IRM program will seek to achieve an appropriate balance between integrated, company-wide information solutions and the freedom necessary to effectively meet programmatic needs. It will emphasize the importance of providing flexibility for rapid and precise response to customer information needs.

A Business Management Systems Improvements Oversight Committee has been established to evaluate the merits of changes in business management systems identified and suggested by a project team. This project team also works in conjunction with the IMTT when possible while striving to meet ORNL objectives. The feasibility of integrating the business planning, prioritization, budget, work authorization, and accounting processes is being studied.

Networking

Networking within ORNL and connectivity to the Internet are key infrastructure elements, made all the more critical by the long lead times required to make significant networking changes. With the completion of the initial phases of the FDDI backbone system, the focus turns to attaching more systems and Ethernet segments to the FDDI network and to continuing the expansion of Ethernet access. SLIP, PPP, and other protocols will be considered for providing Ethernet capability through the extensive, asynchronous SSN network.

Several options are being considered to increase the speed of the connection between the ORNL site and Y-12 site FDDI installations from T1 to T3.

Information Management

ORNL will continue its national leadership in providing scientific and technical information through information centers and databases; the demand for such information is expected to grow during the planning period. Areas of interest include the development of a knowledge-based expert system that assists the Y-12 Plant in internal assessments of environmental regulatory issues; determination of the root cause of an occurrence; performance of environmental surveillance data mapping; and application of hypertext/expert systems for accessing large amounts of diverse information. Furthermore, the Information Management Technology Group will initiate effective communication activities for the education of students, the general public, and scientists in research areas of national significance, such as the Human Genome Program, the Radon Research Program, and the legal and scientific issues originating from regulatory actions and/or mandates. Educational materials such as exhibits, posters, and a multimedia approach including PC-based instruction packages are being investigated.

Automation, centralization, and more effective management of business information will be addressed as part of administrative computing. ISD has developed a strategic plan for supporting the information needs of Energy Systems (ORNL/CF-92/59).

Resources and Initiatives

Major new initiatives and funding requirements for the Center for Computational Sciences [e.g., major item of equipment (MIE) MMES-92-3X] are addressed in Sect. 4, "Summary of Major Initiatives." Central scientific computing is funded primarily through cost recovery from the programmatic funds of users; no MIE-level acquisitions are planned before FY 1996. There is a plan for an out-year acquisition in the MIE class (MIE number: MMES-96-4X), but it is premature to define the precise requirements. Depending on usage levels, open systems may be acquired in the short or intermediate term, but these would be well below the MIE level. Distributed scientific computing resources are provided out of programmatic funds or divisional overhead. No MIE-level acquisitions are planned.

In administrative computing, a client-server implementation of e-mail is being offered to friendly, early users within Energy Systems. It is being supported by C&TS and will be offered at a flat-fee rate, which is expected to be substantially lower than the average e-mail charge to users today. This project will be monitored closely and used as a prototype for advancing client-server implementations of other forms of administrative computing. A business management systems improvements initiative is under way to study the feasibility of integrating the business planning, prioritization, budget, work authorization, and accounting processes. Should the study yield positive results, an acquisition below the MIE level may be necessary.

In the networking area, Energy Systems has proposed the Oak Ridge Federal Integrated Communications Network (ORF-ICN) project. This system will improve the Official Oak Ridge Telephone System (OORTS) with a modern digital switching system with full Integrated Services Digital Network (ISDN) and high-speed fiber-optics capabilities (MIE MMES-95-1). The ORF-ICN is a DOE project that will be managed for DOE by Energy Systems. Personnel resources are being furnished by C&TS; expense funding will be provided by ORNL for services that the Laboratory receives. Some of the MIE funding will cover renovation of existing facilities, such as the space in the basement of Building 4500N that is being supplied by ORNL.

None of the technology transfer partnerships that are now in place require significant additional resources. The needs of future partnerships cannot be anticipated.

The mass storage system for the ARM Program (MIE MMES-93-10X) will be a hierarchical storage system made up of a tightly coupled collection of fast disk storage, staging disk storage, and automated tape libraries using D2 tapes. It will be operated in conjunction with the Center for Computational Sciences. The archive will ultimately receive up to 50 terabytes of data per year, and an equal or larger amount of outgoing traffic is expected as researchers throughout the United States acquire and manipulate these data.

11 • Resource Projections

The Laboratory's organization chart appears in the Appendix. Resource projections are presented in the following tables:

- Table 11.1, Laboratory funding summary,
- Table 11.2, Laboratory personnel summary,
- Table 11.3, funding by assistant secretarial level office,
- Table 11.4, personnel by assistant secretarial level office,
- Table 11.5, resources by program,
- Table 11.6, subcontracting and procurement, and
- Table 11.7, small and disadvantaged business procurement.

Tables 11.1, 11.3, 11.5, and 11.7 present resource projections for budget authority (BA) funding in millions of dollars. These resource projections reflect new BA funding requested in the FY 1995 budget submission documents, adjusted to incorporate any interim guidance. New BA requests are calculated by adding estimates of outstanding commitments and prefinancing to the total cost and then subtracting the prior-year uncosted budget. The inflation escalation factor in BA funding dollars for both FY 1994 and FY 1995 is 4.0%. BA funding dollars for FY 1996 through FY 1999 are reported in constant FY 1994 dollars.

Subcontracting and procurement funding is reported in Table 11.6 as total obligated funds for each fiscal year.

Personnel statistics reported in Tables 11.2 and 11.4 are given as the number of full-time equivalent (FTE) employees.

Table 11.1
Laboratory funding summary by fiscal year
($ in millions—BA)

	1992	1993	1994	1995	1996	1997	1998	1999
DOE effort	435.2	469.3	545.4	648.1	668.4	650.1	650.9	675.2
Work for others	73.9	83.3	91.5	95.1	95.1	95.1	95.1	95.1
Total operating	509.1	552.6	636.9	743.2	763.5	745.2	746.0	770.3
Capital equipment	49.5	40.8	53.2	64.8	97.9	64.9	64.7	62.3
Construction	27.9	60.6	0.0	0.0	0.0	0.0	0.0	0.0
Total Laboratory	586.5	654.0	690.1	808.0	861.4	810.1	810.7	832.6
Proposed construction	0.0	0.0	85.6	192.4	288.9	430.4	574.1	591.6
Total projected funding	586.5	654.0	775.7	1000.4	1150.3	1240.5	1384.8	1424.2

Table 11.2
Laboratory personnel summary by fiscal year
[Full-time equivalent (FTE) employees]

	1992	1993	1994	1995	1996	1997	1998	1999
Direct DOE effort	1625.9	1780.6	1848.8	2001.2	2001.6	1925.3	1910.3	1935.3
Work for others	328.2	382.9	357.1	359.8	359.8	359.8	359.8	359.8
Total technical direct personnel	1954.1	2163.5	2205.9	2361.0	2361.4	2285.1	2270.1	2295.1
Other direct	224.9	298.7	276.8	316.3	333.4	344.1	341.5	290.5
Total direct personnel	2179.0	2462.2	2482.7	2677.3	2694.8	2629.2	2611.6	2585.6
Indirect personnel	2550.0	2650.0	2650.0	2700.0	2700.0	2700.0	2700.0	2700.0
Total Laboratory	4729.0	5112.2	5132.7	5377.3	5394.8	5329.2	5311.6	5285.6

Table 11.3
Funding by assistant secretarial level office by fiscal year
($ in millions—BA)

	1992	1993	1994	1995	1996	1997	1998	1999
Office of Energy Research								
Operating expense	179.1	182.2	204.6	250.5	251.6	256.6	249.6	270.8
Capital equipment	13.9	13.4	39.4	49.7	82.1	48.5	48.1	45.7
Construction	4.6	7.4	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	42.0	129.2	239.5	384.5	505.8	521.0
Total	197.6	203.0	286.0	429.4	573.2	689.6	803.5	865.0
Office of Nuclear Energy								
Operating expense	31.3	32.1	26.1	26.5	26.5	26.5	26.5	26.5
Capital equipment	0.3	0.4	0.8	1.2	1.2	1.2	1.2	1.2
Total	31.6	32.5	26.9	27.7	27.7	27.7	27.7	27.7
Office of New Production Reactors								
Operating expense	0.4	(0.3)	0.0	0.0	0.0	0.0	0.0	0.0
Capital equipment	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	8.8	3.6	0.0	0.0	0.0	0.0	0.0	0.0
Total	10.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Office of Civilian Radioactive Waste Management								
Operating expense	0.6	1.6	2.0	2.1	2.1	2.1	2.1	2.1
Capital equipment	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.6	1.7	2.0	2.1	2.1	2.1	2.1	2.1
Assistant Secretary for Defense Programs								
Operating expense	8.6	9.7	14.2	13.5	13.5	13.5	13.5	13.5
Capital equipment	1.7	3.1	0.5	1.3	1.3	1.3	1.3	1.3
Construction	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
Total	10.3	13.9	14.7	14.8	14.8	14.8	14.8	14.8
Office of Intelligence and National Security								
Operating expense	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Capital equipment	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Assistant Secretary for Energy Efficiency and Renewable Energy								
Operating expense	58.7	66.8	108.4	138.6	138.6	138.6	138.6	138.6
Capital equipment	2.8	3.7	6.1	8.0	8.0	8.0	8.0	8.0
Total	61.5	70.5	114.5	146.6	146.6	146.6	146.6	146.6
Assistant Secretary for Fossil Energy								
Operating expense	9.4	7.5	11.1	13.3	13.3	13.3	13.3	13.3
Capital equipment	0.0	0.0	0.4	0.2	0.2	0.2	0.2	0.2
Total	9.4	7.5	11.5	13.5	13.5	13.5	13.5	13.5
Assistant Secretary for Environment, Safety, and Health								
Operating expense	7.7	7.1	9.5	10.2	10.2	10.2	10.2	10.2
Capital equipment	0.0	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Total	7.7	7.2	9.7	10.3	10.3	10.3	10.3	10.3
Assistant Secretary for Environmental Restoration and Waste Management								
Operating expense	9.8	8.8	10.9	29.3	29.3	5.5	5.5	5.5
Capital equipment	1.4	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Construction	4.9	6.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	16.1	19.3	10.9	29.3	29.3	5.5	5.5	5.5

Table 11.3
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Energy Information Administration								
Operating expense	0.8	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Office of the Associate Deputy Secretary for Field Management								
Operating expense	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Construction	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	0.3	0.3	0.6	0.6	0.6	0.6
Total	0.7	0.4	0.5	0.5	0.8	0.8	0.8	0.8
Assistant Secretary for Policy, Planning and Program Evaluation								
Operating expense	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Federal Energy Regulatory Commission								
Operating expense	2.0	0.5	1.2	1.2	1.2	1.2	1.2	1.2
Assistant Secretary for Congressional, Intergovernmental and International Affairs								
Operating expense	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3
DOE funding from Energy Systems central organizations								
Operating expense	86.4	123.9	129.0	132.0	151.2	151.7	159.5	162.6
Capital equipment	14.2	7.7	1.0	1.0	1.7	2.3	2.5	2.5
Construction	9.0	42.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	43.3	62.9	48.8	45.3	67.7	70.0
Total	109.6	173.8	173.3	195.9	201.7	199.3	229.7	235.1
Subtotal DOE Programs								
Operating expense	401.6	448.1	527.6	628.0	648.3	630.0	630.8	655.1
Capital equipment	35.5	33.1	48.5	61.6	94.7	61.7	61.5	59.1
Construction	27.9	60.6	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	85.6	192.4	288.9	430.4	574.1	591.6
Total	465.0	541.8	661.7	882.0	1031.9	1122.1	1266.4	1305.8
DOE Contractors and Operations Office								
Operating expense	33.6	21.2	17.8	20.1	20.1	20.1	20.1	20.1
Capital equipment	0.0	2.1	3.0	3.0	3.0	3.0	3.0	3.0
Total	33.6	23.3	20.8	23.1	23.1	23.1	23.1	23.1
Total DOE Programs								
Operating expense	435.2	469.3	545.4	648.1	668.4	650.1	650.9	675.2
Capital equipment	35.5	35.2	51.5	64.6	97.7	64.7	64.5	62.1
Construction	27.9	60.6	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	85.6	192.4	288.9	430.4	574.1	591.6
Total	498.6	565.1	682.5	905.1	1055.0	1145.2	1289.5	1328.9
Work for others								
Nuclear Regulatory Commission								
Operating expense	20.5	18.9	20.3	20.0	20.0	20.0	20.0	20.0
Capital equipment	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	20.7	18.9	20.3	20.0	20.0	20.0	20.0	20.0
Department of Defense								
Operating expense	24.9	43.5	40.3	36.2	36.2	36.2	36.2	36.2
Capital equipment	12.2	5.3	1.6	0.1	0.1	0.1	0.1	0.1
Total	37.1	48.8	41.9	36.3	36.3	36.3	36.3	36.3
National Aeronautics and Space Administration								
Operating expense	5.0	5.9	6.2	10.1	10.1	10.1	10.1	10.1

Table 11.3
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Department of Health and Human Services								
Operating expense	3.8	2.7	4.3	4.9	4.9	4.9	4.9	4.9
Capital equipment	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total	3.8	2.8	4.3	4.9	4.9	4.9	4.9	4.9
Environmental Protection Agency								
Operating expense	3.4	1.1	2.2	2.2	2.2	2.2	2.2	2.2
National Science Foundation								
Operating expense	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Federal Emergency Management Agency								
Operating expense	1.3	1.4	1.1	1.0	1.0	1.0	1.0	1.0
Agency for International Development								
Operating expense	0.4	0.1	0.3	0.5	0.5	0.5	0.5	0.5
Department of Transportation								
Operating expense	4.4	4.5	4.1	3.1	3.1	3.1	3.1	3.1
Other Federal agencies								
Operating expense	3.2	(1.2)	5.8	9.4	9.4	9.4	9.4	9.4
Capital equipment	1.6	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total	4.8	(1.0)	5.9	9.5	9.5	9.5	9.5	9.5
Electric Power Research Institute								
Operating expense	2.2	1.8	1.7	1.8	1.8	1.8	1.8	1.8
Other nonfederal agencies								
Operating expense	3.9	5.3	4.2	4.9	4.9	4.9	4.9	4.9
Total Work for Others								
Operating expense	73.9	83.3	91.5	95.1	95.1	95.1	95.1	95.1
Capital equipment	14.0	5.6	1.7	0.2	0.2	0.2	0.2	0.2
Total	87.9	88.9	93.2	95.3	95.3	95.3	95.3	95.3
Total Laboratory								
Operating expense	509.1	552.6	636.9	743.2	763.5	745.2	746.0	770.3
Capital equipment	49.5	40.8	53.2	64.8	97.9	64.9	64.7	62.3
Construction	27.9	60.6	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	85.6	192.4	288.9	430.4	574.1	591.6
Total	586.5	654.0	775.7	1000.4	1150.3	1240.5	1384.8	1424.2

Table 11.4
Personnel by assistant secretarial level office by fiscal year
[Full-time equivalent (FTE) employees]

	1992	1993	1994	1995	1996	1997	1998	1999
Office of Energy Research								
Technical personnel	673.3	728.9	808.7	860.5	857.8	856.6	841.6	865.0
Other direct personnel	95.3	115.4	116.1	177.9	194.2	205.4	202.4	150.7
Total direct personnel	769.0	844.3	924.8	1038.4	1052.0	1062.0	1044.0	1015.7
Office of Nuclear Energy								
Technical personnel	121.8	116.9	83.2	82.9	82.9	82.9	82.9	82.9
Other direct personnel	21.5	27.3	21.3	8.2	8.2	8.2	8.2	8.2
Total direct personnel	143.3	144.2	104.5	91.1	91.1	91.1	91.1	91.1
Office of New Production Reactors								
Technical personnel	1.0	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	0.0
Total direct personnel	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Office of Civilian Radioactive Waste Management								
Technical personnel	5.2	7.8	8.2	9.2	9.2	9.2	9.2	9.2
Other direct personnel	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	7.3	7.8	8.2	9.2	9.2	9.2	9.2	9.2
Assistant Secretary for Defense Programs								
Technical personnel	59.3	62.1	59.2	66.4	66.4	66.4	66.4	66.4
Other direct personnel	0.7	5.0	18.3	9.8	9.8	9.8	9.8	9.8
Total direct personnel	60.0	67.1	77.5	76.2	76.2	76.2	76.2	76.2
Office of Intelligence and National Security								
Technical personnel	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Assistant Secretary for Energy Efficiency and Renewable Energy								
Technical personnel	154.6	184.9	209.5	238.8	238.8	238.8	238.8	238.8
Other direct personnel	4.7	4.9	7.1	10.7	10.7	10.7	10.7	10.7
Total direct personnel	159.3	189.8	216.6	249.5	249.5	249.5	249.5	249.5
Assistant Secretary for Fossil Energy								
Technical personnel	22.3	32.3	36.1	35.9	35.9	35.9	35.9	35.9
Other direct personnel	0.0	2.7	5.0	6.0	6.0	6.0	6.0	6.0
Total direct personnel	22.3	35.0	41.1	41.9	41.9	41.9	41.9	41.9
Assistant Secretary for Environment, Safety, and Health								
Technical personnel	19.9	29.4	29.1	30.5	30.5	30.5	30.5	30.5
Other direct personnel	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Total direct personnel	20.3	29.9	29.7	31.1	31.1	31.1	31.1	31.1
Assistant Secretary for Environmental Restoration and Waste Management								
Technical personnel	38.7	31.2	40.5	97.7	97.7	20.9	20.9	20.9
Other direct personnel	1.6	0.0	0.9	2.8	2.8	1.6	1.6	1.6
Total direct personnel	40.3	31.2	41.4	100.5	100.5	22.5	22.5	22.5
Energy Information Administration								
Technical personnel	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8

Table 11.4
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Office of the Associate Deputy Secretary for Field Management								
Technical personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total direct personnel	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Assistant Secretary for Policy, Planning and Program Evaluation								
Technical personnel	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Other direct personnel	0.0	0.5	0.3	0.3	0.3	0.3	0.3	0.3
Total direct personnel	8.0	10.5	10.3	10.3	10.3	10.3	10.3	10.3
Federal Energy Regulatory Commission								
Technical personnel	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Other direct personnel	0.0	0.8	0.9	0.7	0.7	0.7	0.7	0.7
Total direct personnel	4.9	5.8	5.9	5.7	5.7	5.7	5.7	5.7
Assistant Secretary for Congressional, Intergovernmental and International Affairs								
Technical personnel	0.2	0.4	1.1	0.9	0.9	0.9	0.9	0.9
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.2	0.4	1.1	0.9	0.9	0.9	0.9	0.9
DOE funding from Energy Systems central organizations								
Technical personnel	418.6	454.5	470.3	473.0	476.1	477.8	477.8	479.4
Other direct personnel	41.2	76.9	71.3	67.6	68.4	69.1	69.5	70.2
Total direct personnel	459.8	531.4	541.6	540.6	544.5	546.9	547.3	549.6
Subtotal DOE Programs								
Technical personnel	1542.6	1686.1	1788.1	1941.1	1941.5	1865.2	1850.2	1875.2
Other direct personnel	170.3	239.2	247.1	290.0	307.1	317.8	315.2	264.2
Total direct personnel	1712.9	1925.3	2035.2	2231.1	2248.6	2183.0	2165.4	2139.4
DOE Contractors and Operations Office								
Technical personnel	83.3	94.5	60.7	60.1	60.1	60.1	60.1	60.1
Other direct personnel	16.7	8.9	7.5	6.2	6.2	6.2	6.2	6.2
Total direct personnel	100.0	103.4	68.2	66.3	66.3	66.3	66.3	66.3
Total DOE Programs								
Technical personnel	1625.9	1780.6	1848.8	2001.2	2001.6	1925.3	1910.3	1935.3
Other direct personnel	187.0	248.1	254.6	296.2	313.3	324.0	321.4	270.4
Total direct personnel	1812.9	2028.7	2103.4	2297.4	2314.9	2249.3	2231.7	2205.7
Work for others								
Nuclear Regulatory Commission								
Technical personnel	62.7	69.3	71.8	72.3	72.3	72.3	72.3	72.3
Other direct personnel	20.5	9.9	6.4	6.9	6.9	6.9	6.9	6.9
Total direct personnel	83.2	79.2	78.2	79.2	79.2	79.2	79.2	79.2
Department of Defense								
Technical personnel	166.3	178.9	151.0	135.4	135.4	135.4	135.4	135.4
Other direct personnel	10.1	17.1	14.9	12.5	12.5	12.5	12.5	12.5
Total direct personnel	176.4	196.0	165.9	147.9	147.9	147.9	147.9	147.9
National Aeronautics and Space Administration								
Technical personnel	24.3	25.5	29.1	32.0	32.0	32.0	32.0	32.0
Other direct personnel	0.4	21.8	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	24.7	47.3	29.1	32.0	32.0	32.0	32.0	32.0

Table 11.4
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Department of Health and Human Services								
Technical personnel	22.3	21.5	21.9	22.2	22.2	22.2	22.2	22.2
Other direct personnel	0.9	0.9	0.2	0.0	0.0	0.0	0.0	0.0
Total direct personnel	23.2	22.4	22.1	22.2	22.2	22.2	22.2	22.2
Environmental Protection Agency								
Technical personnel	9.0	17.6	18.0	12.5	12.5	12.5	12.5	12.5
Other direct personnel	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	9.7	17.6	18.0	12.5	12.5	12.5	12.5	12.5
National Science Foundation								
Technical personnel	1.6	6.3	4.5	4.3	4.3	4.3	4.3	4.3
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.7	6.3	4.5	4.3	4.3	4.3	4.3	4.3
Federal Emergency Management Agency								
Technical personnel	5.0	5.4	4.2	3.9	3.9	3.9	3.9	3.9
Other direct personnel	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	5.4	5.4	4.2	3.9	3.9	3.9	3.9	3.9
Agency for International Development								
Technical personnel	2.4	0.3	2.4	2.5	2.5	2.5	2.5	2.5
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.4	0.3	2.4	2.5	2.5	2.5	2.5	2.5
Department of Transportation								
Technical personnel	6.2	13.9	18.7	23.3	23.3	23.3	23.3	23.3
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	6.2	13.9	18.7	23.3	23.3	23.3	23.3	23.3
Other Federal agencies								
Technical personnel	10.5	0.3	2.9	20.4	20.4	20.4	20.4	20.4
Other direct personnel	2.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	13.3	0.5	2.9	20.4	20.4	20.4	20.4	20.4
Electric Power Research Institute								
Technical personnel	8.1	13.0	9.9	7.7	7.7	7.7	7.7	7.7
Other direct personnel	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total direct personnel	9.1	13.2	10.1	7.9	7.9	7.9	7.9	7.9
Other nonfederal agencies								
Technical personnel	9.8	30.9	22.7	23.3	23.3	23.3	23.3	23.3
Other direct personnel	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Total direct personnel	10.8	31.4	23.2	23.8	23.8	23.8	23.8	23.8
Total Work for Others								
Technical personnel	328.2	382.9	357.1	359.8	359.8	359.8	359.8	359.8
Other direct personnel	37.9	50.6	22.2	20.1	20.1	20.1	20.1	20.1
Total direct personnel	366.1	433.5	379.3	379.9	379.9	379.9	379.9	379.9
Total Laboratory								
Technical personnel	1954.1	2163.5	2205.9	2361.0	2361.4	2285.1	2270.1	2295.1
Other direct personnel	224.9	298.7	276.8	316.3	333.4	344.1	341.5	290.5
Total Laboratory direct personnel	2179.0	2462.2	2482.7	2677.3	2694.8	2629.2	2611.6	2585.6
Total Laboratory indirect personnel	2550.0	2650.0	2650.0	2700.0	2700.0	2700.0	2700.0	2700.0
Total Laboratory personnel	4729.0	5112.2	5132.7	5377.3	5394.8	5329.2	5311.6	5285.6

Table 11.5
Resources by program by fiscal year
($ in millions—BA)

	1992	1993	1994	1995	1996	1997	1998	1999
Office of Energy Research								
Magnetic Fusion—AT								
Total operating	28.0	31.0	33.0	35.0	35.0	35.0	35.0	35.0
Capital equipment	2.2	2.4	2.5	2.8	2.8	2.8	2.8	2.8
Total program	30.2	33.4	35.5	37.8	37.8	37.8	37.8	37.8
Technical personnel	70.6	73.0	74.0	75.0	75.0	75.0	75.0	75.0
Other direct personnel	27.7	30.0	32.0	33.0	33.0	33.0	33.0	33.0
Total direct personnel	98.3	103.0	106.0	108.0	108.0	108.0	108.0	108.0
High Energy Physics—KA[a]								
Total operating	0.4	0.4	1.0	0.9	0.9	0.9	0.9	0.9
Technical personnel	2.1	2.4	3.8	3.8	3.8	3.8	3.8	3.8
Other direct personnel	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.4	2.4	3.8	3.8	3.8	3.8	3.8	3.8
Nuclear Physics—KB								
Total operating	13.6	10.4	12.8	14.2	14.2	14.2	14.2	14.2
Capital equipment	1.5	0.9	1.4	1.2	1.2	1.2	1.2	1.2
Construction	0.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Total program	15.7	12.1	15.2	15.4	15.4	15.4	15.4	15.4
Technical personnel	57.4	45.2	50.2	52.8	52.8	52.8	52.8	52.8
Other direct personnel	5.4	9.9	10.1	11.2	11.2	11.2	11.2	11.2
Total direct personnel	62.8	55.1	60.3	64.0	64.0	64.0	64.0	64.0
Basic Energy Sciences—KC								
Total operating	102.7	104.0	118.7	160.1	160.2	164.2	156.2	176.4
Capital equipment	8.1	7.3	10.7	21.4	55.2	21.5	21.0	18.5
Construction	2.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	26.0	92.1	169.9	323.1	485.1	500.3
Total program	113.1	112.3	155.4	273.6	385.3	508.8	662.3	695.2
Technical personnel	441.6	452.5	497.1	553.5	550.8	549.6	534.6	558.0
Other direct personnel	58.4	67.0	65.0	124.8	141.1	152.3	149.3	97.6
Total direct personnel	500.0	519.5	562.1	678.3	691.9	701.9	683.9	655.6
Energy Research Analyses—KD								
Total operating	2.6	1.9	2.2	2.6	2.6	2.6	2.6	2.6
Technical personnel	3.1	4.0	4.4	3.4	3.4	3.4	3.4	3.4
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	3.1	4.0	4.4	3.4	3.4	3.4	3.4	3.4
Multiprogram Energy Laboratory Facility Support—KG								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Capital equipment	0.0	0.2	10.2	11.1	11.1	11.1	11.1	11.1
Construction (MGPF)	5.6	5.6	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	6.0	10.3	16.8	9.9	9.9	9.9
Total program	5.6	5.8	16.2	21.4	27.9	21.0	21.0	21.0
Technical personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Biological and Environmental Research—KP								
Total operating	27.9	29.0	28.0	29.0	30.0	31.0	32.0	33.0
Capital equipment	2.0	2.4	2.5	2.6	1.2	1.3	1.4	1.5
Proposed construction	0.0	0.0	0.0	16.0	42.0	40.7	0.0	0.0
Total program	29.9	31.4	30.5	47.6	73.2	73.0	33.4	34.5
Technical personnel	94.0	106.5	126.1	123.4	123.4	123.4	123.4	123.4
Other direct personnel	2.5	3.4	3.9	3.8	3.8	3.8	3.8	3.8
Total direct personnel	96.5	109.9	130.0	127.2	127.2	127.2	127.2	127.2
Superconducting Super Collider—KS								
Total operating	0.1	0.0	0.5	0.6	0.6	0.6	0.6	0.6
Capital equipment	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	0.2	0.0	0.5	0.6	0.6	0.6	0.6	0.6
Technical personnel	0.4	1.6	2.4	2.4	2.4	2.4	2.4	2.4
Other direct personnel	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.3	1.6	2.4	2.4	2.4	2.4	2.4	2.4
University & Science Education—KT								
Total operating	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	1.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Technology Transfer—KU								
Total operating	2.1	2.0	4.7	3.8	3.8	3.8	3.8	3.8
Capital equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	2.1	2.0	4.7	3.8	3.8	3.8	3.8	3.8
Technical personnel	2.3	15.4	21.5	15.6	15.6	15.6	15.6	15.6
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.4	15.4	21.5	15.6	15.6	15.6	15.6	15.6
University & Science Education—KV								
Total operating	1.1	1.4	1.7	2.3	2.3	2.3	2.3	2.3
Technical personnel	0.7	3.3	5.1	6.5	6.5	6.5	6.5	6.5
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.7	3.3	5.1	6.5	6.5	6.5	6.5	6.5
Landlord								
Total operating	0.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
GPE capital equipment	0.0	0.2	12.1	10.6	10.6	10.6	10.6	10.6
GPP construction	(3.9)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Proposed GPP construction	0.0	0.0	9.0	10.8	10.8	10.8	10.8	10.8
Total program	(3.9)	2.2	23.1	23.4	23.4	23.4	23.4	23.4
Technical personnel	0.0	24.1	24.1	24.1	24.1	24.1	24.1	24.1
Other direct personnel	0.0	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Total direct personnel	0.0	29.2	29.2	29.2	29.2	29.2	29.2	29.2
Total Office of Energy Research								
Operating expense	179.1	182.2	204.6	250.5	251.6	256.6	249.6	270.8
Capital equipment	13.9	13.4	39.4	49.7	82.1	48.5	48.1	45.7
Construction	4.6	7.4	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	42.0	129.2	239.5	384.5	505.8	521.0
Total program	197.6	203.0	286.0	429.4	573.2	689.6	80.35	837.5

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Technical personnel	673.7	728.9	808.7	860.5	857.8	856.6	841.6	865.0
Other direct personnel	95.3	115.4	116.1	240.1	256.4	267.6	264.6	212.9
Total direct personnel	699.0	844.3	1178.6	1358.7	1372.3	1382.3	1364.3	1336.0
Office of Nuclear Energy								
Nuclear Energy R&D—AF								
Total operating	23.1	21.0	15.0	15.0	15.0	15.0	15.0	15.0
Capital equipment	0.3	0.4	0.8	1.2	1.2	1.2	1.2	1.2
Total program	23.4	21.4	15.8	16.2	16.2	16.2	16.2	16.2
Technical personnel	98.9	84.4	51.0	50.7	50.7	50.7	50.7	50.7
Other direct personnel	15.1	18.3	12.3	8.2	8.2	8.2	8.2	8.2
Total direct personnel	114.0	102.7	63.3	58.9	58.9	58.9	58.9	58.9
Naval Reactors—AJ								
Total operating	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Technical personnel	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Uranium Enrichment—CD								
Total operating	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Technical personnel	2.9	2.6	2.3	2.3	2.3	2.3	2.3	2.3
Other direct personnel	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	3.1	2.6	2.3	2.3	2.3	2.3	2.3	2.3
Isotope Production and Distribution Program—ST								
Total operating	7.6	10.0	10.0	10.4	10.4	10.4	10.4	10.4
Technical personnel	9.7	29.5	29.5	29.5	29.5	29.5	29.5	29.5
Other direct personnel	0.2	9.0	9.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	9.9	38.5	38.5	29.5	29.5	29.5	29.5	29.5
Total Office of Nuclear Energy								
Operating expense	31.3	32.1	26.1	26.5	26.5	26.5	26.5	26.5
Capital equipment	0.3	0.4	0.8	1.2	1.2	1.2	1.2	1.2
Total	31.6	32.5	26.9	27.7	27.7	27.7	27.7	27.7
Technical personnel	121.8	116.9	83.2	82.9	82.9	82.9	82.9	82.9
Other direct personnel	21.5	27.3	21.3	8.2	8.2	8.2	8.2	8.2
Total direct personnel	143.3	144.2	104.5	91.1	91.1	91.1	91.1	91.1
Office of New Production Reactors								
New Production Reactors—NP								
Total operating	0.4	(0.3)	0.0	0.0	0.0	0.0	0.0	0.0
Capital equipment	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	8.8	3.6	0.0	0.0	0.0	0.0	0.0	0.0
Total program	10.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	1.0	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	0.0
Total direct personnel	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total Office of New Production Reactors								
Total operating	0.4	(0.3)	0.0	0.0	0.0	0.0	0.0	0.0
Capital equipment	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Construction	8.8	3.6	0.0	0.0	0.0	0.0	0.0	0.0
Total program	10.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Technical personnel	1.0	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	0.0
Total direct personnel	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Office of Civilian Radioactive Waste Management								
Nuclear Waste Fund—DB								
Total operating	0.6	1.6	2.0	2.1	2.1	2.1	2.1	2.1
Capital equipment	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total program	0.6	1.7	2.0	2.1	2.1	2.1	2.1	2.1
Technical personnel	5.2	7.8	8.2	9.2	9.2	9.2	9.2	9.2
Other direct personnel	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	7.3	7.8	8.2	9.2	9.2	9.2	9.2	9.2
Total Office of Civilian Radioactive Waste Management								
Total operating	0.6	1.6	2.0	2.1	2.1	2.1	2.1	2.1
Capital equipment	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total program	0.6	1.7	2.0	2.1	2.1	2.1	2.1	2.1
Technical personnel	5.2	7.8	8.2	9.2	9.2	9.2	9.2	9.2
Other direct personnel	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	7.3	7.8	8.2	9.2	9.2	9.2	9.2	9.2
Assistant Secretary for Defense Programs								
Weapons Activities—GB								
Total operating	0.4	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Technical personnel	1.6	1.8	1.4	1.4	1.4	1.4	1.4	1.4
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.6	1.8	1.4	1.4	1.4	1.4	1.4	1.4
Materials Production—GE								
Total operating	8.2	9.5	14.0	13.2	13.2	13.2	13.2	13.2
Capital equipment	1.7	3.1	0.5	1.3	1.3	1.3	1.3	1.3
Construction	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
Total program	9.9	13.7	14.5	14.5	14.5	14.5	14.5	14.5
Technical personnel	57.7	60.3	57.8	65.0	65.0	65.0	65.0	65.0
Other direct personnel	0.7	5.0	18.3	9.8	9.8	9.8	9.8	9.8
Total direct personnel	58.4	65.3	76.1	74.8	74.8	74.8	74.8	74.8
Total Assistant Secretary for Defense Programs								
Total operating	8.6	9.7	14.2	13.5	13.5	13.5	13.5	13.5
Capital equipment	1.7	3.1	0.5	1.3	1.3	1.3	1.3	1.3
Construction	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
Total program	10.3	13.9	14.7	14.8	14.8	14.8	14.8	14.8
Technical personnel	59.3	62.1	59.2	66.4	66.4	66.4	66.4	66.4
Other direct personnel	0.7	5.0	18.3	9.8	9.8	9.8	9.8	9.8
Total direct personnel	60.0	67.1	77.5	76.2	76.2	76.2	76.2	76.2
Office of Intelligence and National Security								
Nuclear Safeguards and Security—GD								
Total operating	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Capital equipment	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total program	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Total Office of Intelligence and National Security								
Total operating	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Capital equipment	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total program	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Assistant Secretary for Energy Efficiency and Renewable Energy								
Electric Energy Systems—AK								
Total operating	9.4	11.7	20.6	26.6	26.6	26.6	26.6	26.6
Capital equipment	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2
Total program	9.7	11.9	20.9	26.8	26.8	26.8	26.8	26.8
Technical personnel	20.3	24.2	28.4	30.1	30.1	30.1	30.1	30.1
Other direct personnel	0.2	0.7	1.9	2.2	2.2	2.2	2.2	2.2
Total direct personnel	20.5	24.9	30.3	32.3	32.3	32.3	32.3	32.3
Energy Storage Systems—AL								
Total operating	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	1.4	1.6	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.4	1.6	0.0	0.0	0.0	0.0	0.0	0.0
Geothermal Energy —AM								
Total operating	0.1	1.1	0.7	0.1	0.1	0.1	0.1	0.1
Technical personnel	5.4	5.7	3.0	0.9	0.9	0.9	0.9	0.9
Other direct personnel	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0
Total direct personnel	5.4	6.0	3.1	0.9	0.9	0.9	0.9	0.9
Hydropower—CE								
Total operating	0.2	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Technical personnel	0.6	1.2	1.9	1.8	1.8	1.8	1.8	1.8
Other direct personnel	0.0	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Total direct personnel	0.6	1..4	2.2	2.1	2.1	2.1	2.1	2.1
Solar Energy—EB								
Total operating	4.5	4.1	5.6	8.1	8.1	8.1	8.1	8.1
Capital equipment	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total program	4.6	4.2	5.7	8.2	8.2	8.2	8.2	8.2
Technical personnel	10.1	10.7	12.2	13.2	13.2	13.2	13.2	13.2
Other direct personnel	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Total direct personnel	10.4	11.0	12.6	13.7	13.7	13.7	13.7	13.7
Buildings Sector—EC								
Total operating	9.3	10.4	14.5	16.1	16.1	16.1	16.1	16.1
Capital equipment	0.3	1.1	1.1	0.8	0.8	0.8	0.8	0.8
Total program	9.6	11.5	15.6	16.9	16.9	16.9	16.9	16.9
Technical personnel	28.8	37.4	40.9	45.1	45.1	45.1	45.1	45.1
Other direct personnel	0.8	2.0	0.6	0.8	0.8	0.8	0.8	0.8
Total direct personnel	29.6	39.4	41.5	45.9	45.9	45.9	45.9	45.9

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Industrial Sector—ED								
Total operating	8.1	9.4	16.3	17.5	17.5	17.5	17.5	17.5
Capital equipment	0.1	0.5	1.5	1.9	1.9	1.9	1.9	1.9
Total program	8.2	9.9	17.8	19.4	19.4	19.4	19.4	19.4
Technical personnel	25.5	32.1	41.4	47.7	47.7	47.7	47.7	47.7
Other direct personnel	0.7	0.0	0.2	0.2	0.2	0.2	0.2	0.2
Total direct personnel	26.2	32.1	41.6	47.9	47.9	47.9	47.9	47.9
Transportation Sector—EE								
Total operating	22.6	26.7	45.1	64.5	64.5	64.5	64.5	64.5
Capital equipment	2.0	1.8	3.1	5.0	5.0	5.0	5.0	5.0
Total program	24.6	28.5	48.2	69.5	69.5	69.5	69.5	69.5
Technical personnel	54.1	61.5	71.1	89.4	89.4	89.4	89.4	89.4
Other direct personnel	0.2	0.0	1.7	4.6	4.6	4.6	4.6	4.6
Total direct personnel	54.3	61.5	72.8	94.0	94.0	94.0	94.0	94.0
Technical and Financial Assistance—EF								
Total operating	2.5	2.1	3.8	3.8	3.8	3.8	3.8	3.8
Technical personnel	5.6	5.7	6.4	6.4	6.4	6.4	6.4	6.4
Other direct personnel	2.5	1.4	1.9	2.1	2.1	2.1	2.1	2.1
Total direct personnel	8.1	7.1	8.3	8.5	8.5	8.5	8.5	8.5
Utility Sector—EK								
Total operating	1.2	0.9	1.3	1.4	1.4	1.4	1.4	1.4
Technical personnel	2.8	4.8	4.2	4.2	4.2	4.2	4.2	4.2
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.8	4.8	4.2	4.2	4.2	4.2	4.2	4.2
Total Assistant Secretary for Energy Efficiency and Renewable Energy								
Operating expense	58.7	66.8	108.4	138.6	138.6	138.6	138.6	138.6
Capital equipment	2.8	3.7	6.1	8.0	8.0	8.0	8.0	8.0
Total	61.5	70.5	114.5	146.6	146.6	146.6	146.6	146.6
Technical personnel	154.6	184.9	209.5	238.8	238.8	238.8	238.8	238.8
Other direct personnel	4.7	4.9	7.1	10.7	10.7	10.7	10.7	10.7
Total direct personnel	159.3	189.8	216.6	249.5	249.5	249.5	249.5	249.5
Assistant Secretary for Fossil Energy								
Coal—AA								
Total operating	6.2	6.1	7.8	10.3	10.3	10.3	10.3	10.3
Capital equipment	0.0	0.0	0.4	0.2	0.2	0.2	0.2	0.2
Total program	6.2	6.1	8.2	10.5	10.5	10.5	10.5	10.5
Technical personnel	19.2	21.7	22.7	23.1	23.1	23.1	23.1	23.1
Other direct personnel	0.0	2.0	2.8	3.6	3.6	3.6	3.6	3.6
Total direct personnel	19.2	23.7	25.5	26.7	26.7	26.7	26.7	26.7
Petroleum—AC								
Total operating	0.1	0.7	2.1	2.0	2.0	2.0	2.0	2.0
Capital equipment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	0.1	0.7	2.1	2.0	2.0	2.0	2.0	2.0
Technical personnel	0.4	5.2	7.7	7.8	7.8	7.8	7.8	7.8
Other direct personnel	0.0	0.7	2.2	2.4	2.4	2.4	2.4	2.4
Total direct personnel	0.4	5.9	9.9	10.2	10.2	10.2	10.2	10.2

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Innovative Clean Coal Technology—AZ								
Total operating	3.0	0.4	0.8	0.6	0.6	0.6	0.6	0.6
Technical personnel	1.6	3.3	3.7	3.3	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	0.0
Total direct personnel	1.6	3.3	3.7	3.3	3.3	3.3	3.3	3.3
Strategic Petroleum Reserve—SA								
Total operating	0.1	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Technical personnel	1.1	2.1	2.0	1.7	1.7	1.7	1.7	1.7
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.1	2.1	2.0	1.7	1.7	1.7	1.7	1.7
Total Assistant Secretary for Fossil Energy								
Operating expense	9.4	7.5	11.1	13.3	13.3	13.3	13.3	13.3
Capital equipment	0.0	0.0	0.4	0.2	0.2	0.2	0.2	0.2
Total program	9.4	7.5	11.5	13.5	13.5	13.5	13.5	13.5
Technical personnel	22.3	32.3	36.1	35.9	35.9	35.9	35.9	35.9
Other direct personnel	0.0	2.7	5.0	6.0	6.0	6.0	6.0	6.0
Total direct personnel	22.3	35.0	41.1	41.9	41.9	41.9	41.9	41.9
Assistant Secretary for Environment, Safety, and Health								
Environmental Research and Development—HA								
Total operating	7.6	7.0	9.4	10.1	10.1	10.1	10.1	10.1
Capital equipment	0.0	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Total program	7.6	7.1	9.6	10.2	10.2	10.2	10.2	10.2
Technical personnel	19.8	28.6	28.6	30.0	30.0	30.0	30.0	30.0
Other direct personnel	0.1	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Total direct personnel	19.9	29.1	29.2	30.6	30.6	30.6	30.6	30.6
Epidemiological Activities—HR								
Total operating	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Technical personnel	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Office of Security Evaluations—HS								
Total operating	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Technical personnel	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Other direct personnel	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Policy and Management—Nuclear Energy—KK								
Total operating	3.2	3.2	5.1	5.3	5.3	5.3	5.3	5.3
Technical personnel	10.5	15.8	19.4	21.5	21.5	21.5	21.5	21.5
Other direct personnel	2.0	2.2	2.2	2.3	2.3	2.3	2.3	2.3
Total direct personnel	12.5	18.0	21.6	23.8	23.8	23.8	23.8	23.8
Office of Nuclear Safety—NS								
Total operating	0.6	1.7	1.9	1.9	1.9	1.9	1.9	1.9
Technical personnel	0.8	4.0	5.0	6.0	6.0	6.0	6.0	6.0
Other direct personnel	0.0	2.2	2.3	2.3	2.3	2.3	2.3	2.3
Total direct personnel	0.8	6.2	7.3	8.3	8.3	8.3	8.3	8.3

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Total Assistant Secretary for Environment, Safety, and Health								
Total operating	11.5	12.0	16.5	17.4	17.4	17.4	17.4	17.4
Capital equipment	0.0	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Total program	11.5	12.1	16.7	17.5	17.5	17.5	17.5	17.5
Technical personnel	31.2	49.2	53.5	58.0	58.0	58.0	58.0	58.0
Other direct personnel	2.4	4.9	5.1	5.2	5.2	5.2	5.2	5.2
Total direct personnel	33.6	54.1	58.6	63.2	63.2	63.2	63.2	63.2
Energy Information Administration								
National Energy Information System—TA								
Operating expense	0.8	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Total Energy Information Administration								
Operating expense	0.8	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Office of the Associate Deputy Secretary for Field Management								
In-House Energy Management—WB								
Total operating	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Construction	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	0.3	0.3	0.6	0.6	0.6	0.6
Total program	0.7	0.4	0.5	0.5	0.8	0.8	0.8	0.8
Technical personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total direct personnel	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total Office of the Associate Deputy Secretary for Field Management								
Total operating	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Construction	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	0.3	0.3	0.6	0.6	0.6	0.6
Total program	0.7	0.4	0.5	0.5	0.8	0.8	0.8	0.8
Technical personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other direct personnel	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total direct personnel	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Assistant Secretary for Policy, Planning and Program Evaluation								
Policy, Planning, and Analysis—PE								
Total operating	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Technical personnel	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Other direct personnel	0.0	0.5	0.3	0.3	0.3	0.3	0.3	0.3
Total direct personnel	8.0	10.5	10.3	10.3	10.3	10.3	10.3	10.3
Total Assistant Secretary for Policy, Planning and Program Evaluation								
Total operating	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Technical personnel	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Other direct personnel	0.0	0.5	0.3	0.3	0.3	0.3	0.3	0.3
Total direct personnel	8.0	10.5	10.3	10.3	10.3	10.3	10.3	10.3

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Federal Energy Regulatory Commission								
Federal Energy Regulatory Commission—VR								
Total operating	2.0	0.5	1.2	1.2	1.2	1.2	1.2	1.2
Technical personnel	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Other direct personnel	0.0	0.8	0.9	0.7	0.7	0.7	0.7	0.7
Total direct personnel	4.9	5.8	5.9	5.7	5.7	5.7	5.7	5.7
Total Federal Energy Regulatory Commission								
Total operating	2.0	0.5	1.2	1.2	1.2	1.2	1.2	1.2
Technical personnel	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Other direct personnel	0.0	0.8	0.9	0.7	0.7	0.7	0.7	0.7
Total direct personnel	4.9	5.8	5.9	5.7	5.7	5.7	5.7	5.7
Assistant Secretary for Congressional, Intergovernmental and International Affairs								
Emergency Preparedness—NB								
Total operating	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	0.2	0.4	1.1	0.9	0.9	0.9	0.9	0.9
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.2	0.4	1.1	0.9	0.9	0.9	0.9	0.9
Total Assistant Secretary for Congressional, Intergovernmental and International Affairs								
Total operating	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Technical personnel	0.2	0.4	1.1	0.9	0.9	0.9	0.9	0.9
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	0.2	0.4	1.1	0.9	0.9	0.9	0.9	0.9
Assistant Secretary for Environmental Restoration and Waste Management								
EM Isotope Facility Shutdown—EX								
Total operating	9.6	8.8	8.4	23.8	23.8	0.0	0.0	0.0
Construction	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	10.4	8.8	8.4	23.8	23.8	0.0	0.0	0.0
Technical personnel	37.0	31.2	31.0	76.8	76.8	0.0	0.0	0.0
Other direct personnel	1.5	0.0	0.2	1.2	1.2	0.0	0.0	0.0
Total direct personnel	38.5	31.2	31.2	78.0	78.0	0.0	0.0	0.0
Other								
Total operating	0.2	0.0	2.5	5.5	5.5	5.5	5.5	5.5
GPE capital equipment	1.4	4.5	0.0	0.0	0.0	0.0	0.0	0.0
GPP construction	4.1	6.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	5.7	10.5	2.5	5.5	5.5	5.5	5.5	5.5
Technical personnel	1.7	0.0	9.5	20.9	20.9	20.9	20.9	20.9
Other direct personnel	0.1	0.0	0.7	1.6	1.6	1.6	1.6	1.6
Total direct personnel	1.8	0.0	10.2	22.5	22.5	22.5	22.5	22.5
Total Assistant Secretary for Environmental Restoration and Waste Management								
Total operating	9.8	8.8	10.9	29.3	29.3	5.5	5.5	5.5
Capital equipment	1.4	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Construction	4.9	6.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	16.1	19.3	10.9	29.3	29.3	5.5	5.5	5.5
Technical personnel	38.7	31.2	40.5	97.7	97.7	20.9	20.9	20.9
Other direct personnel	1.6	0.0	0.9	2.8	2.8	1.6	1.6	1.6
Total direct personnel	40.3	31.2	41.4	100.5	100.5	22.5	22.5	22.5

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
DOE Funding from Energy Systems Central Organizations								
EM Corrective Activities								
Total operating	0.7	0.5	1.0	1.0	0.5	0.6	0.0	0.0
Capital equipment	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
Construction	2.4	15.9	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	18.0	26.1	6.0	0.0	0.0	0.0
Total program	3.1	17.5	19.0	27.1	6.5	0.6	0.0	0.0
Technical personnel	15.9	18.0	3.0	3.0	1.5	1.6	0.0	0.0
Other direct personnel	0.5	1.3	0.1	0.7	0.3	0.3	0.0	0.0
Total direct personnel	16.4	19.3	3.1	3.7	1.8	1.9	0.0	0.0
Environmental Restoration								
Total operating	33.7	44.4	48.0	48.1	50.3	50.3	50.3	50.3
Capital equipment	9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total program	43.6	44.4	48.0	48.1	50.3	50.3	50.3	50.3
Technical personnel	144.9	155.4	171.5	182.8	185.8	185.8	185.8	185.8
Other direct personnel	11.4	20.0	22.9	22.8	23.3	23.3	23.3	23.3
Total direct personnel	156.3	175.4	194.4	205.6	209.1	209.1	209.1	209.1
Waste Management								
Total operating	35.3	61.0	55.7	58.0	75.5	75.9	84.3	87.4
Capital equipment	4.3	6.6	1.0	1.0	1.7	2.3	2.5	2.5
Construction	6.6	26.3	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	25.3	36.8	42.8	45.3	67.7	70.0
Total program	46.2	93.9	82.0	95.8	120.0	123.5	154.4	159.9
Technical personnel	211.8	224.3	235.6	228.6	230.2	231.8	233.4	235.0
Other direct personnel	26.4	52.5	45.1	40.5	41.2	41.9	42.6	43.3
Total direct personnel	238.2	276.8	280.7	269.1	271.4	273.7	276.0	278.3
Technology Development								
Total operating	16.7	18.0	24.3	24.9	24.9	24.9	24.9	24.9
Technical personnel	46.0	56.8	60.2	58.6	58.6	58.6	58.6	58.6
Other direct personnel	2.9	3.1	3.2	3.6	3.6	3.6	3.6	3.6
Total direct personnel	48.9	59.9	63.4	62.2	62.2	62.2	62.2	62.2
Total DOE Funding from Energy Systems Central Organizations								
Operating expense	86.4	123.9	129.0	132.0	151.2	151.7	159.5	162.6
Capital equipment	14.2	7.7	1.0	1.0	1.7	2.3	2.5	2.5
Construction	9.0	42.2	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	43.3	62.9	48.8	45.3	67.7	70.0
Total	109.6	173.8	173.3	195.9	201.7	199.3	229.7	235.1
Technical personnel	418.6	454.5	470.3	473.0	476.1	477.8	477.8	479.4
Other direct personnel	41.2	76.9	71.3	67.6	68.4	69.1	69.5	70.2
Total direct personnel	459.8	531.4	541.6	540.6	544.5	546.9	547.3	549.6
Subtotal—DOE Programs								
Operating expense	401.6	448.1	527.6	628.0	648.3	630.0	630.8	655.1
Capital equipment	35.5	33.1	48.5	61.6	94.7	61.7	61.5	59.1
Construction	27.9	60.6	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	85.6	192.4	288.9	430.4	574.1	591.6
Total	465.0	541.8	661.7	882.0	1031.9	1122.1	1266.4	1305.8
Technical personnel	1542.6	1686.1	1788.1	1941.1	1941.5	1865.2	1850.2	1875.2
Other direct personnel	170.3	239.2	247.1	290.0	307.1	317.8	315.2	264.2
Total direct personnel	1712.9	1925.3	2035.2	2231.1	2248.6	2183.0	2165.4	2139.4

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
DOE Contractors and Operations Office								
Operating expense	33.6	21.2	17.8	20.1	20.1	20.1	20.1	20.1
Capital equipment	0.0	2.1	3.0	3.0	3.0	3.0	3.0	3.0
Total	33.6	23.3	20.8	23.1	23.1	23.1	23.1	23.1
Technical personnel	83.3	94.5	60.7	60.1	60.1	60.1	60.1	60.1
Other direct personnel	16.7	8.9	7.5	6.2	6.2	6.2	6.2	6.2
Total direct personnel	100.0	103.4	68.2	66.3	66.3	66.3	66.3	66.3
Total DOE Programs								
Operating expense	435.2	471.3	631.2	745.2	765.5	747.2	748.1	772.6
Capital equipment	35.5	35.2	51.5	64.6	97.7	64.7	64.5	62.1
Construction	27.9	60.6	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	85.6	192.4	288.9	430.4	574.1	591.6
Total	498.6	567.1	768.3	1002.2	1152.1	1242.3	1386.7	1426.3
Technical personnel	1625.9	1780.6	1848.8	2001.2	2001.6	1925.3	1910.3	1935.3
Other direct personnel	187.0	248.1	254.6	296.2	313.3	324.0	321.4	270.4
Total direct personnel	1812.9	2028.7	2103.4	2297.4	2314.9	2249.3	2231.7	2205.7
Work for others								
Nuclear Regulatory Commission								
Operating expense	20.5	18.9	20.3	20.0	20.0	20.0	20.0	20.0
Capital equipment	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	20.7	18.9	20.3	20.0	20.0	20.0	20.0	20.0
Technical personnel	62.7	69.3	71.8	72.3	72.3	72.3	72.3	72.3
Other direct personnel	20.5	9.9	6.4	6.9	6.9	6.9	6.9	6.9
Total direct personnel	83.2	79.2	78.2	79.2	79.2	79.2	79.2	79.2
Department of Defense								
Operating expense	24.9	43.5	40.3	36.2	36.2	36.2	36.2	36.2
Capital equipment	12.2	5.3	1.6	0.1	0.1	0.1	0.1	0.1
Total	37.1	48.8	41.9	36.3	36.3	36.3	36.3	36.3
Technical personnel	166.3	178.9	151.0	135.4	135.4	135.4	135.4	135.4
Other direct personnel	10.1	17.1	14.9	12.5	12.5	12.5	12.5	12.5
Total direct personnel	176.4	196.0	165.9	147.9	147.9	147.9	147.9	147.9
National Aeronautics and Space Administration								
Operating expense	5.0	5.9	6.2	10.1	10.1	10.1	10.1	10.1
Technical personnel	24.3	25.5	29.1	32.0	32.0	32.0	32.0	32.0
Other direct personnel	0.4	21.8	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	24.7	47.3	29.1	32.0	32.0	32.0	32.0	32.0
Department of Health and Human Services								
Operating expense	3.8	2.7	4.3	4.9	4.9	4.9	4.9	4.9
Capital equipment	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total	3.8	2.8	4.3	4.9	4.9	4.9	4.9	4.9
Technical personnel	22.3	21.5	21.9	22.2	22.2	22.2	22.2	22.2
Other direct personnel	0.9	0.9	0.2	0.0	0.0	0.0	0.0	0.0
Total direct personnel	23.2	22.4	22.1	22.2	22.2	22.2	22.2	22.2
Environmental Protection Agency								
Operating expense	3.4	1.1	2.2	2.2	2.2	2.2	2.2	2.2
Technical personnel	9.0	17.6	18.0	12.5	12.5	12.5	12.5	12.5
Other direct personnel	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	9.7	17.6	18.0	12.5	12.5	12.5	12.5	12.5

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
National Science Foundation								
Operating expense	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Technical personnel	1.6	6.3	4.5	4.3	4.3	4.3	4.3	4.3
Other direct personnel	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	1.7	6.3	4.5	4.3	4.3	4.3	4.3	4.3
Federal Emergency Management Agency								
Operating expense	1.3	1.4	1.1	1.0	1.0	1.0	1.0	1.0
Technical personnel	5.0	5.4	4.2	3.9	3.9	3.9	3.9	3.9
Other direct personnel	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	5.4	5.4	4.2	3.9	3.9	3.9	3.9	3.9
Agency for International Development								
Operating expense	0.4	0.1	0.3	0.5	0.5	0.5	0.5	0.5
Technical personnel	2.4	0.3	2.4	2.5	2.5	2.5	2.5	2.5
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	2.4	0.3	2.4	2.5	2.5	2.5	2.5	2.5
Department of Transportation								
Operating expense	4.4	2.8	4.1	3.1	3.1	3.1	3.1	3.1
Technical personnel	6.2	13.9	18.7	23.3	23.3	23.3	23.3	23.3
Other direct personnel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	6.2	13.9	18.7	23.3	23.3	23.3	23.3	23.3
Other Federal agencies								
Total operating	3.2	(1.2)	5.8	9.4	9.4	9.4	9.4	9.4
Capital equipment	1.6	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Total program	4.8	(1.0)	5.9	9.5	9.5	9.5	9.5	9.5
Technical personnel	10.5	0.3	2.9	20.4	20.4	20.4	20.4	20.4
Other direct personnel	2.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Total direct personnel	13.3	0.5	2.9	20.4	20.4	20.4	20.4	20.4
Electric Power Research Institute								
Operating expense	2.2	1.8	1.7	1.8	1.8	1.8	1.8	1.8
Technical personnel	8.1	13.0	9.9	7.7	7.7	7.7	7.7	7.7
Other direct personnel	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total direct personnel	9.1	13.2	10.1	7.9	7.9	7.9	7.9	7.9
Other nonfederal agencies								
Total operating	3.9	5.3	4.2	4.9	4.9	4.9	4.9	4.9
Technical personnel	9.8	30.9	22.7	23.3	23.3	23.3	23.3	23.3
Other direct personnel	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Total direct personnel	10.8	31.4	23.2	23.8	23.8	23.8	23.8	23.8
Total Work for Others								
Total operating	73.9	83.3	91.5	95.1	95.1	95.1	95.1	95.1
Capital equipment	14.0	5.6	1.7	0.2	0.2	0.2	0.2	0.2
Total	87.9	88.9	93.2	95.3	95.3	95.3	95.3	95.3
Technical personnel	328.2	382.9	357.1	359.8	359.8	359.8	359.8	359.8
Other direct personnel	37.9	50.6	22.2	20.1	20.1	20.1	20.1	20.1
Total direct personnel	366.1	433.5	379.3	379.9	379.9	379.9	379.9	379.9

Table 11.5
(continued)

	1992	1993	1994	1995	1996	1997	1998	1999
Total Program Resources								
Operating expense	509.1	552.6	636.9	743.2	763.5	745.2	746.0	770.3
Capital equipment	49.5	40.8	53.2	64.8	97.9	64.9	64.7	62.3
Construction	27.9	60.6	0.0	0.0	0.0	0.0	0.0	0.0
Proposed construction	0.0	0.0	85.6	192.4	288.9	430.4	574.1	591.6
Total	586.5	654.0	775.7	1000.4	1150.3	1240.5	1384.8	1424.2
Technical personnel	1954.1	2163.5	2205.9	2361.0	2361.4	2285.1	2270.1	2295.1
Other direct personnel	224.9	298.7	276.8	316.3	333.4	344.1	341.5	290.5
Total direct personnel	2179.0	2462.2	2482.7	2677.3	2694.8	2629.2	2611.6	2585.6

[a]Does not include funding request for SSC Laboratory/GEM collaborative effort.

Table 11.6
Subcontracting and procurement by fiscal year by fiscal year
($ in millions—obligated)

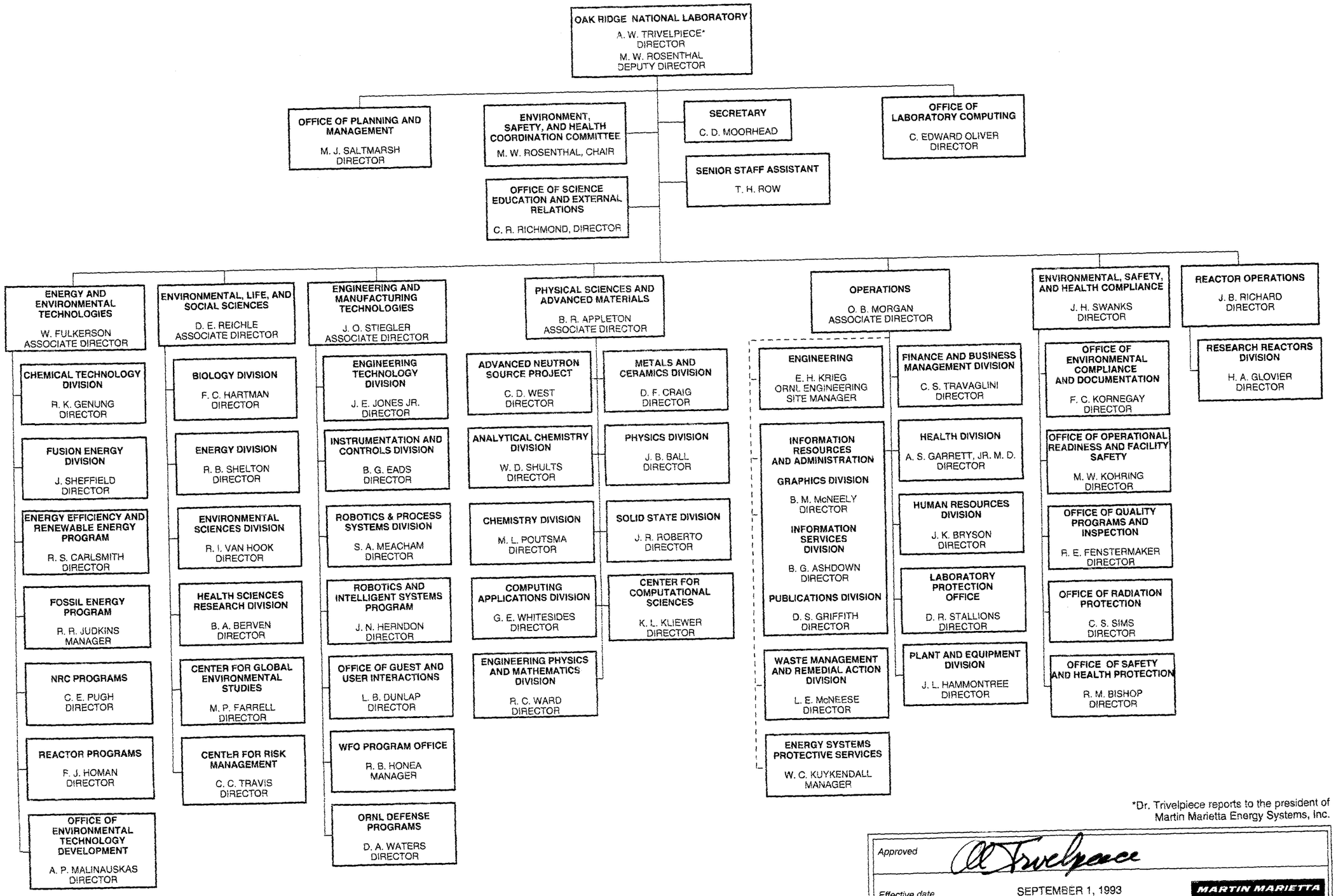
	1992	1993[a]	1994[a]	1995[a]
Universities	25.0	27.2	29.3	30.1
All others	140.2	147.1	153.8	162.2
Transfers to other DOE facilities	3.7	3.0	3.1	3.2
Total external subcontracts and procurements	168.9	177.3	186.2	195.5

[a]Estimated.

Table 11.7
Estimated small and disadvantaged business procurement by fiscal year

	1992	1993
Total funding ($ in millions—BA)	8.4	15.9
Percentage of annual procurement (%)	4.9	9.0

Appendix



*Dr. Trivelpiece reports to the president of Martin Marietta Energy Systems, Inc.

Approved	A. Trivelpiece
Effective date	SEPTEMBER 1, 1993

MARTIN MARIETTA

Abbreviations

AA	affirmative action
ADANS	AMC Deployment Analysis Systems
ADEPT	Assisting the Deployment of Energy Practices and Technologies
ADS	activity data sheet
AEOD	NRC Office of Analysis and Evaluation of Operational Data
AEP	Advanced Energy Projects
AFCESA	Air Force Civil Engineering Support Agency
AFM	atomic force microscope
AIC	Advanced Industrial Concepts
AID	U.S. Agency for International Development
AiS	Adventures in Supercomputing
ALERT	Associated Laboratories for Excellence in Radiation Technology
AMC	Air Mobility Command
AMTEX	American Textile Partnership
ANL	Argonne National Laboratory
ANS	Advanced Neutron Source
ARC	Appalachian Regional Commission
ARL	Army Research Laboratory
ARM	Atmospheric Radiation Measurement
ARPA	Advanced Research Projects Agency
ATF	Advanced Toroidal Facility
ATSDR	Agency for Toxic Substances and Disease Registry
B&W	Babcock and Wilcox
BA	budget authority
BES	Basic Energy Sciences
BFDP	Biofuels Feedstock Development Program
BNL	Brookhaven National Laboratory
BRDC	Bioprocessing Research and Development Center
BRF	Bioprocessing Research Facility
BTC	Buildings Technology Center
BTESM	Building Thermal Envelope Systems and Materials
BWR	boiling-water reactor
C&TS	Computing and Telecommunications Services organization
CAMA	Center for Advanced Microstructural Analysis
CAS	Chemical Abstracts Service
CBI	Cross Bar Interconnect
CBS	Center for Biological Sciences
C-CAP	Coast Watch Change Analysis Program
CCM2	Community Climate Model
CCS	Center for Computational Sciences
CCTP	Clean Coal Technology Project
CDIAC	Carbon Dioxide Information Analysis Center
CD-NSWC	Carderock Division–Naval Surface Warfare Center

CEF	Critical Experiments Facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERN	Conseil Européen pour Recherche Nucléaire
CERR	Center for Excellence in Research Reactors
CESAR	Center for Engineering Systems Advanced Research
CFC	chlorofluorocarbon
CHAMMP	Computer Hardware, Advanced Mathematics, and Model Physics
CNG	compressed natural gas
COEECT	Committee on Energy Efficiency Commerce and Trade
CORECT	Committee on Renewable Energy Commerce and Trade
CRADA	cooperative research and development agreement
CRM	Center for Risk Management
CSAM	Center for Study of Advanced Materials
CTSB	Computing and Telecommunications Standards Board
CURE	Chemical Unit Record Estimates
D&D	decontamination and decommissioning
DAAC	Distributed Active Archive Center
DMS	Division of Materials Science
DNA	deoxyribonucleic acid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE-BES	U.S. Department of Energy, Office of Basic Energy Sciences
DOE-DP	U.S. Department of Energy, Assistant Secretary for Defense Programs
DOE-EE	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
DOE-EM	U.S. Department of Energy, Office of Environmental Restoration and Waste Management
DOE-ER	U.S. Department of Energy, Office of Energy Research
DOE-HQ	U.S. Department of Energy, Headquarters
DOE-NE	U.S. Department of Energy, Office of Nuclear Energy
DOE-NP	U.S. Department of Energy, Office of New Production Reactors
DOE-OFE	U.S. Department of Energy, Office of Fusion Energy
DOE-OHER	U.S. Department of Energy, Office of Health and Environmental Research
DOE-ORO	U.S. Department of Energy, Oak Ridge Operations Office
DOSAR	Dosimetry Applications Research
DOT	U.S. Department of Transportation
D-T	deuterium-tritium
ECAO-CIN	EPA Environmental Criteria and Assessment Office, Cincinnati
ECR	electron cyclotron resonance
EEO	equal employment opportunity
EEO/AA	equal employment opportunity/affirmative action
EGF	epidermal growth factor
EIA	Energy Information Administration
EIS	environmental impact statement
ELSS	Environmental, Life, and Social Sciences
e-mail	electronic mail
EMIC	Environmental Mutagen Information Center
EMP	electromagnetic pulse
EOS	Earth Observing System
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ER LTT	Energy Research Laboratory Technology Transfer Program
ES&H	environmental, safety, and health
ES&HC	environmental, safety, and health compliance
ESD	Environmental Sciences Division
ETI	Education Technology Institute

FARS	Future Armor Rearm System
FCCSET	Federal Coordinating Council for Science, Engineering, and Technology
FDDI	fiber-distributed data interface
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FFA	Federal Facilities Agreement
FHWA	Federal Highway Administration
FICA	Facility Interface Capability Assessment
FIS	fluoroimmunosensor
FMIF	Fusion Materials Irradiation Facility
FT	Fourier transform
FTE	full-time equivalent
FTMS	Fourier transform mass spectrometry
FUSRAP	Formerly Utilized Sites Remedial Action Project
FWG	folded waveguide
FWP	field work proposal
FY	fiscal year
GAX	generator–absorber–heat exchanger
GCM	general circulation model
GDR	giant dipole resonance
GEIS	generic environmental impact statement
GEM	Gamma, Electron, and Muon (SSC detector collaboration); National Consortium for Graduate Degrees for Minorities in Engineering, Inc.
GIS	geographical information system
GLCA/ACM	Great Lakes Colleges Association/Associated Colleges of the Midwest
GPE	general-purpose equipment
GPF	general-purpose facility
GPP	general plant project
GRAIL	Gene Recognition and Analysis Internet Link
GSF	gross square feet
GWPO	Groundwater Program Office
HASRD	Health and Safety Research Division (now Health Sciences Research Division)
HAZWRAP	Hazardous Waste Remedial Action Program
HBCU	historically black college or university
HCFC	hydrochlorofluorocarbon
HEAST	Health Effects Assessment Summary Tables
HERMIES	Hostile Environment Robotic Machine Intelligent Experiment Series
HFIR	High Flux Isotope Reactor
HGMIS	Human Genome Management Information System
HHIRF	Holifield Heavy Ion Research Facility
HHS	U.S. Department of Health and Human Services
HiPPI	High-Performance Parallel Interface
HPCC	High Performance Computing and Communications
HPCRC	High Performance Computing Research Center
HPRR	Health Physics Research Reactor
HSRD	Health Sciences Research Division
HSSI	NRC Heavy-Section Steel Irradiation Program
HSST	NRC Heavy-Section Steel Technology Program
HTML	High Temperature Materials Laboratory
HVAC	heating, ventilation, and air conditioning
HWR	heavy-water reactor
I&C	instrumentation and controls
IAEA	International Atomic Energy Agency
ICM	interim corrective measure
ICRF	ion cyclotron range of frequencies

ICRP	International Commission on Radiological Protection
IDB	Integrated Data Base
IFR	Integral Fast Reactor
IMTT	Information Management Task Team
I/O	input/output
IRA	Information Resources and Administration
IRM	information resource management
IRP	Installation Restoration Program; Integrated Resource Planning
ISD	Information Services Division
ITER	International Thermonuclear Experimental Reactor
JASPER	Japanese/American Shielding Program of Experimental Research
JET	Joint European Torus
JIEE	Joint Institute for Energy and Environment
JWS	joint work statement
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LDRD	Laboratory Directed R&D
LEU	low-enriched uranium
LHD	Large Helical Device
LLLW	liquid low-level waste
LLNL	Lawrence Livermore National Laboratory
LWR	light-water reactor
M&C	Metals and Ceramics
M&O	management and operating
MALD	matrix-assisted laser deposition
MEI	minority educational institution
MEL-FS	Multiprogram Energy Laboratories Facilities Support
MHD	magnetohydrodynamic
MHTGR	modular high-temperature gas-cooled reactor
MIE	major item of equipment
MIT	Massachusetts Institute of Technology
MMES	Martin Marietta Energy Systems, Inc.
MODIL	Manufacturing Operations Development and Integration Laboratory
MOU	memorandum of understanding
MPP	massively parallel processing
MS&E	Materials Science and Engineering
MSC	Military Sealift Command
MSO	molten salt oxidation
MTMC	Military Traffic Management Command
MVST-CIP	Melton Valley Storage Tanks Capacity Increase Project
NASA	National Aeronautics and Space Administration
NCA&TSU	North Carolina A&T State University
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCHGR	National Center for Human Genome Research
NCI	National Cancer Institute
NDE	nondestructive evaluation
NEPA	National Environmental Policy Act
NERC	NEPA Environmental Review and Compliance
NERP	National Environmental Research Park
NERSC	National Energy Research Supercomputer Center
NES	National Energy Strategy
NICHHD	National Institute for Child Health and Human Development
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health

NIST	National Institute for Standards and Technology
NMR	nuclear magnetic resonance
NMSS	NRC Office of Nuclear Material Safety and Safeguards
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPR	New Production Reactor
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NRR	NRC Office of Nuclear Reactor Regulation
NSF	National Science Foundation
NTP	Numerical Tokamak Project
OCRWM	DOE Office of Civilian Radioactive Waste Management
OEA	Office of Environmental Analysis
OGUI	Office of Guest and User Interactions
OHEA	EPA Office of Health and Environmental Assessment
OHER	Office of Health and Environmental Research
OLC	Office of Laboratory Computing
OORTS	Official Oak Ridge Telephone System
ORAM	optical random access memory
ORDC	Oak Ridge Detector Center
OREIS	Oak Ridge Environmental Information System
ORELA	Oak Ridge Electron Linear Accelerator
OREN	Oak Ridge Educational Network
ORF-ICN	Oak Ridge Federal Integrated Communications Network
ORGSBS	Oak Ridge Graduate School of Biomedical Sciences
ORIC	Oak Ridge Isochronous Cyclotron
ORISE	Oak Ridge Institute for Science and Education
ORNL	Oak Ridge National Laboratory
ORSOAR	Oak Ridge Synchrotron Organization for Advanced Research
ORTA	Office of Research and Technology Applications
ORTRAN	Oak Ridge Transportation Technology Center
OSHA	Occupational Safety and Health Administration
OTD	Office of Technology Development
PBX-M	Princeton Beta Experiment, Modified
PC	personal computer
PCA	Pool Critical Assembly
PCB	polychlorinated biphenyl
PEIS	programmatic environmental impact statement
PER	Program for Ecosystem Research
PETC	Pittsburgh Energy Technology Center
PHENIX	Photon Electron New Heavy Ion Experiment
PICS	Partnership in Computational Science
ppb	part per billion
PPPL	Princeton Plasma Physics Laboratory
PSTM	photon scanning tunneling microscope
PVM	Parallel Virtual Machine
R&D	research and development
RADCAL	Radiation Calibration Laboratory
RADCON	Radiation Control
RAP	remedial action project
RAPIC	Remedial Action Program Information Center
RCRA	Resource Conservation and Recovery Act
RDDT&E	research, development, demonstration, testing, and evaluation
REDC	Radiochemical Engineering Development Center
RES	NRC Office of Nuclear Regulatory Research

rf	radio frequency
RFTF	Radio Frequency Test Facility
RHIC	Relativistic Heavy Ion Collider
RI	remedial investigation
RIB	radioactive ion beam
RIED	radiation-induced electrical degradation
RISP	Robotics and Intelligent Systems Program
RMS	Recoil Mass Spectrometer
RNA	ribonucleic acid
RSIC	Radiation Shielding Information Center
RTG	radioisotope thermoelectric generator
Rubisco	ribulose bisphosphate carboxylase/oxygenase
S&M	surveillance and maintenance
SACAM	Saturday Academy of Computing and Mathematics
SAHEP	Southern Association for High Energy Physics
SAS	NRC Surveillance Data Base, Analysis, and Standardization program
SCSS	Sequence Coding and Search System
SDC	Solenoidal Detector Collaboration
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
SEED	Summer Educational Experience for the Disadvantaged
SEER	ORNL Office of Science Education and External Relations
SERS	Science and Engineering Research Semester
SFMP	Surplus Facilities Management Program
SFT	Super Fixed Target
SFUP	Strategic Facilities Upgrade Program
SHaRE	Shared Research Equipment
SMAC	Surface Modification and Characterization
SMAC/CRC	Surface Modification and Characterization/Collaborative Research Center
SMART	Science/Math Action for Revitalized Teaching
SPR	Strategic Petroleum Reserve
SRS	Savannah River Site
SSC	Superconducting Super Collider
SSN	System Select Network
ST	Spherical Tokamak
START	Small Tight-Aspect-Ratio Tokamak
STM	scanning tunneling microscope
SURA	Southeastern Universities Research Association
SWSA	Solid Waste Storage Area
TACT	Technology Area Coordinating Team
TEXTOR	Tokamak Experiment for Technology Oriented Research
TFTR	Tokamak Fusion Test Reactor
TGF-β	transforming growth factor β
TIRC	Toxicology Information Response Center
TPX	Tokamak Physics Experiment
TQM	Total Quality Management
TRU	transuranic
TSR-II	Tower Shielding Reactor II
TSU	Tennessee State University
TVA	Tennessee Valley Authority
ULCP	University Laboratory Cooperative Program
UMTRAP	Uranium Mill Tailings Remedial Action Project
USAEP	U.S.-Asia Environmental Partnership
USDA	U.S. Department of Agriculture
USTRANSCOM	U.S. Army Transportation Command

UT	The University of Tennessee
UTK	The University of Tennessee at Knoxville
UV-B	ultraviolet B
VOC	volatile organic compound
WAG	waste area grouping
WDC-A	World Data Center–A for Atmospheric Trace Gases
WFO	work for others
WHPP	Waste Handling and Packaging Plant
WIPP	Waste Isolation Pilot Plant
WRP	Waste Reduction Program
WVNS	West Valley Nuclear Services
3-D	three-dimensional

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9.2	ORNL-DWG 92Z-6525A
9.3	ORNL-DWG 92Z-6526B
9.4	ORNL-DWG 92Z-6527B
9.5	ORNL-DWG 92Z-6528A
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